Cognitive Implications of an Economic Approach to Classic Maya Exchange

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Abstract

The objective of this thesis is to explore the notion of *extended mind*, specifically how dynamic social phenomena, such as social interaction, can be seen to constitute a cognitive process. To do this it is explained that not only do representations form in the minds of individuals through an individual's nervous system and body, but that representations can also be seen to form in the minds of individuals through participation in social institutions. The social institution with which this thesis is concerned is exchange, and a case study of Classic Maya ground stone exchange serves as an illustration of how the notion of social institutions as sources of cognition can be applied to the archaeological record.

The view of cognition adopted in this thesis is based in part on recent advances in cognitive scientific research, which proposes that cognition arises from dynamical systems to which individuals are attuned. These dynamical systems are thereby considered cognitive systems. Much cognitive research has focused on cognition that arises via the nervous system or motor actions of individuals. This thesis proposes that social systems can be seen to form dynamical systems to which people are attuned and, as such, social systems can also be regarded as cognitive systems or, more accurately, as supra-individual cognitive systems. Supra-individual cognitive systems generate representations — a phenomenon I refer to as *internalization* — that manifest themselves in the social environment as well as in the individual brain. In turn, once representations become mentally processed by an individual, they can be expressed through action affecting the functional organization of

the supra-individual cognitive system; I refer to this phenomenon as *externalization.*

One implication of this thesis is that archaeologists can become involved in lines of inquiry that generate hypotheses about representations experienced by people in the past. Representations proposed to have been experienced by people in the past can be rigorously described — that is, described in a way that can be critically examined — by mathematically modeling and analyzing supra-individual cognitive systems that can be inferred to have existed in the past. In this thesis, the view of cognition I employ and the methodology for realizing this view of cognition constitute the first steps toward a cognitive archaeology that is concerned with the modeling and analysis of supra-individual cognitive systems.

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Preface

To contextualize the ideas presented here, it is important to explain how I became interested in cognition. Because the idea for this research is closely tied to my experiences in the environment in which I conducted my fieldwork, it is relevant to describe my study area and how my research resulted in my interest in the topic of cognition.

I first began work with the Maya Mountains Archaeological Project (MMAP) in the Maya Mountains[1] of southern Belize in March of 1994 as an undergraduate. The MMAP was a multi-year National Geographic funded project headed by Dr. Peter Dunham of Cleveland State University. The MMAP's purpose was to investigate a little known region characterized in the literature as a backwater of little significance in ancient times (Hammond 1975:105). The project followed up on exploratory research in the region (Graham 1984; Shipley and Graham 1984) that indicated instead that the ancient Maya ex-

[1]The Maya Mountains make up the only significant topographical relief on the Yucatan platform (West 1964:70-73; Wright *et al.* 1959). The Maya Mountains run along a southwest-northeast axis in the interior of Belize. The northeast end of the range is located in the present day Cayo District of Belize while the southwest end of the chain extends into neighboring Guatemala. Along this axis, the Maya Mountains chain is approximately 150 kilometers long and about 75 kilometers wide. The highest point, Doyle's Delight, is approximately 1,200 meters above sea level.

ploited the Maya Mountains for rocks, minerals,[2] as well as biota.[3]

Because of the multidisciplinary focus, the project included geologists and biologists whose primary purpose was to look for rocks, minerals, and biota that the ancient Maya would have valued and therefore would have wanted to exploit. This crossing of disciplines not only facilitated the project in its objective, which was to shed light on ancient Maya occupation in the region, but it also benefited the scientists in their own respective fields. Geologists and biologists were allowed to use the infrastructure of the MMAP to carry on their own subprojects in a region that is difficult to penetrate.[4] As a result of the infrastructure that the MMAP provided, several new species of birds, snakes, fish, and plants were discovered, including an archaic strain of *cacao* that is not found outside the Maya Mountains (Dunham *et al* 1992-2000).

As archaeologists on the project, our objective was to explore the region

[2]Because the Maya Mountains exhibit no value in terms of industrial mineral resources (Dixon 1956; Graham 1994) or extensive cultivable land (Wright *et al.* 1959), the mountains are uninhabited and commercially unexploited today. It is not until we shed our contemporary views that we see that the Maya Mountains zone comprises a wide range of mineral and biotic resources that provided attractive opportunities for resource exploitation in the past (i.e., in the context of a non-globally oriented market).

[3]The Maya Mountains have a high annual rainfall, which approaches five meters. It also retains cool temperatures, which can get as low as 4°C. For this reason, the Maya Mountains of southern Belize support a wide range of flora and fauna that are not common in the rest of Central America. As one of the two last Pleistocene refuges on Earth (the other being the Amazon Basin) (Dunham *et al* 1998), the Maya Mountains harbor several biological species that have become extinct elsewhere.

[4]The Maya Mountains are not imposing in the sense of height; however, they do constitute a formidable area to penetrate. Due to the extremely rugged terrain, the mountain range is geographically isolated from the rest of the Maya Lowlands and is, therefore, difficult to traverse. Hernando Cortes discovered this fact when he lost well over two-thirds of his horses crossing the western flanks of the Maya Mountains in 1525 (Sharer 1994:736).

for communities that would have exploited the resources in the Maya Mountains. When sites were discovered, we cleared them of low vegetation and mapped them. Small-scale excavations in the region were only started in the later years of the project when the reconnaissance phase of the project was completed. As a result of the work conducted by the MMAP, we discovered over 18 new sites — most of these modest sized communities, but with nearly all of the trappings (e.g. settlement features) of important Classic Maya polities.

The Maya Mountains constituted a microcosm of Classic Maya civilization, in which inter-community (polity) interaction could be analyzed within a bounded area. Every community was situated in an alluvial pocket[5] circumscribed by high cliffs in an extremely rugged karstic environment. As a result, topography constrained settlement in such a way that the boundaries of communities could be delineated, with interconnections represented by waterways and fossil drainages. The implication was that multiple communities could be studied as interacting systems. At another level, I saw the inter-community arrangement as a network or circuit in which the communities were the nodes, and the drainages, were the routes of interaction.

In a given three-month season, the MMAP managed three to four arduous three-week expeditions. From our base camp in Big Falls in the Toledo District, it took several hours of driving to arrive at the foot of the Maya Mountains in pick-up trucks loaded with K'ekchi and Mopan Maya guides, scientists, and supplies. It then involved a difficult two-day hike/climb with

[5]The rivers and streams draining the mountains cut steep courses, and deposition of alluvium is limited to relatively small pockets, at least until the rivers reach the coastal plain, where more extensive alluvial deposition is possible (Wright *et al* 1959). Alluvium is important for growing crops and it had important consequences for the development of ancient settlements in the Maya Mountains.

heavy packs into the convoluted karstic interior of the Maya Mountains. Due to the heat and humidity, and the sheer exertion involved in getting through the rugged terrain to the base-of-operations camp, some members of the project had to return to Big Falls. In later years, however, the exertion involved in getting to the base-of-operations camp was greatly alleviated with British military helicopter support.

Initially, when I began my Ph.D. research, what interested me was how Maya civilization could have arisen in such harsh environmental conditions. Given my background in mathematics, I was interested in using mathematics to model interaction among communities to shed light specifically on the economic conditions underlying Maya society in the region. Later, my modeling revealed to me that what was being modeled resembled what is known as a *neural network* (Rao and Rao 1995). This had far reaching implications, because the equations that govern neural dynamics are the same equations used to describe how cognition emerges from a network.

As I later discovered, all *dynamical systems* can be conceived of as having rudimentary cognitive capacity from an information processing standpoint, and this means that social systems in general, if shown to constitute credible dynamical systems, may be seen to have cognitive capability. One has only to verify via modeling and testing that the social systems one is hypothesizing as dynamical systems can be seen to comprise *credible* dynamical systems. The implications of acceding to this point go well beyond the implications that systems theory held for archaeology from the 1960s to the present, which mainly held the system as either an unverifiable hypothesis or as a conceptual tool. Since I propose that the hypothesis of a social system as a dynamical system can be verified to some extent depending on the social system, it should be possible to reconstruct the information that was being processed by the social system for the ancient people being studied. What emerges is the realization that some social systems may be conceived of as cognitive systems and the modeling of these systems can be used to gain insight into the minds attuned to the systems. My objective in this thesis, therefore, is to take the first steps toward building a model in which cognition can be seen as extending into the social world, thereby making the study of certain social institutions, such as exchange systems, a part of the study of cognition.

My case study serves as an illustration of how these first steps can be taken toward a comprehensive model of cognition and of how a new conception of cognition resulting from these first steps can be applied. The Maya Mountains serve as a laboratory in my study, and the archaeology of Maya Mountains communities serves as a means of providing insight into the general subjects of cognition and society.

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Chapter 1

Introduction: Situating the Thesis Objective

1.1 Research Question

Archaeological data are used to model interaction among communities in the Maya Mountains to shed light on the regional economy. The process of modeling reveals that the interaction among the communities can be seen to constitute a *dynamical system*. Because all dynamical systems inherently have rudimentary cognitive capability — they process information (i.e. dynamical systems have *memory* in which information can be stored and from which information may be recalled) — and because the exchange network illuminated by the archaeological data reflects social interaction, my objective in this thesis is to show how cognition can be seen to extend to the social world. The further implication is that studying the genesis of social institutions[1] such as exchange systems can be conceived of as a part of the study of

[1] *institution*: A custom, practice, relationship, or behavioral pattern of importance in the life of a community or society. *The American Heritage Dictionary of the English*

cognition. (Please refer to *Glossary* for definitions of key terms used.) My archaeological case study serves to illustrate how a view of cognition can be formulated that is applicable to archaeological practice. The Maya Mountains serve in my study as a laboratory, and the archaeology of the Maya Mountains communities serves as a means for shedding light on the subjects of cognition and society.

1.2 Different Approaches to the Study of Cognition

The subject matter of cognition is commonly regarded to be studied by psychologists. However, computer scientists, mathematicians, and engineers, or what I refer to as specialists in information processing, also study cognition. Though psychologists and information processing specialists study the same phenomenon, namely cognition, they are often concerned with studying different aspects of cognition and they therefore tend to take different approaches to the study of cognition.

Psychologists are primarily concerned with an approach to cognition that can be related to the way humans think or behave. Psychologists are often counselors and, for this, knowledge of cognition as it relates to the human brain is necessary. For some psychologists, the object of analysis is human behavior, whereas for others the object of analysis is the neurons that are firing and consequently producing representations in the human brain. Often, though, psychologists are interested in how humans process information only so far as it illuminates why humans behave the way that they do. Data regarding an individual's cognitive capabilities are usually collected by the

Language, Third Edition. Houghton Mifflin, Boston, 1992.

psychologist through observing and interacting with the subject.

Specialists in information processing, on the other hand, deal with the mechanics of information processing and, hence, cognition. The study of information processing originated out of an interest in the human brain (Turing 1950) but eventually evolved into a distinct field, referred to as *neural dynamics* (Wu 1999). The information processing approach to cognition deals with examining the ways in which nodes interact in a network; it analyzes interaction to determine the conditions under which cognition (i.e. information processing capability) is produced or effected.

The psychological and information processing approaches differ with respect to focus. Whereas psychologists study cognition in the context of the biochemistry and individual behavior of human beings, specialists in the area of information processing view cognition in terms that do not require a human physiological *substrate* in order to produce cognition. Cognition instead extends conceptually beyond human beings to artificial intelligence as well. Specialists in information processing approach the nature of cognition in a context that can include, but is not limited to, human beings.

Cognition does not need to be defined archetypically as physiological or psychological. Cognition arises in nervous systems, machines, and in essentially any substrate where the functional mechanisms that evoke cognitive capability are present (e.g. social institutions, as we shall see in Chapter 7).

In this thesis, I adopt an information processing approach to the study of cognition. Although archaeological information can be seen to reflect human behavior, neither humans nor their behavior can be observed in ways that permit inferences to be drawn according to the terms of a psychological approach to cognition. To put it simply, the living human substrate which is required of the psychological approach is absent. An information processing approach, however, permits cognition to be studied in just such a context as archaeology, in which the living human substrate is missing.

Thus, the way information is processed can theoretically be abstracted from an archaeological context, and in my case I will propose a mathematical means of abstraction.

1.3 The Thesis Objective

My objective is to describe how cognition can be seen to emerge from interacting participants or groups of participants comprising a social institution. The kind of institution on which I will focus, and which is represented in my archaeological data from the Maya Mountains, is inter-community exchange. It will be shown that exchange in this circumstance can be conceived of as a source of cognition independent of the kind that is generated by the human brain. Given the nature of the evidence, we cannot make a provable connection to the living, operating human brain, but we can observe the effects of the interaction of the humans who once lived and at least make theoretically supportable connections to the living human brain.

Exchange is both interactive (goods exchange hands) and social (involves communities of individuals that see themselves as part of a society). The cognition that potentially emerges from interaction of this kind I shall term "supra-individual cognition". Supra-individual cognition, however, is not unaffected by individual cognition (generated by the brain), nor is individual cognition unaffected by supra-individual cognition. To understand how supra-individual cognition can be seen to affect individual cognition and in turn how individual cognition can be seen to affect supra-individual cognition, I offer an explanation of how the conceptual gap between the two forms of cognition can be bridged and how in doing this a comprehensive way of envisioning human cognition emerges. This new way of envisioning cognition reveals important implications with regards to key social theoretical views utilized in archaeology and anthropology.

To accomplish this thesis objective, the following steps are followed:

- Cognitive research and the direction in which it is heading is reviewed. Much of my thesis is dedicated to looking at cognitive research historically and how, as time goes on, philosophers and cognitive scientists are coming to recognize the fact that cognition is much more pervasive than some had originally thought possible. Research supporting the pervasiveness of cognition is discussed.

- A mathematical model is used to describe a Classic Maya ground stone exchange system that once operated in the Maya Mountains of southern Belize, and an economic analysis of the exchange system and its model is conducted. My description and analysis of the model and the exchange system demonstrate that exchange can be regarded as a source of cognition, thus supporting a view of the pervasiveness of cognition. If enough information is known about how social, political, and economic systems operated, then archaeologists may be able to reconstruct aspects of past human mind frames.

- A comprehensive means of envisioning cognition is proposed by considering the evidence for the pervasiveness of cognition. The notion of the pervasiveness of cognition leads to a new evaluation of cognition, and the first step is taken toward developing a model that can account for the pervasiveness of cognition. A model that accounts for the pervasiveness of cognition entails a new conception of cognition which can be seen to impact several social theoretical issues in archaeology and anthropology. I explore the influence of this conception on two social theoretical issues: the epidemiological view of cultural traits in cultural evolutionary theory, and agency.

1.3.1 The Three Parts to the Thesis

The steps that are followed to achieve my thesis objective form three major parts, each part containing two to three chapters.

Part I

Part I of the thesis provides the background to the history of the study of cognition. Its purpose is to show the archaeologist how conceptions of cognition have changed through time and what the current outlook is on cognition. It is important to dedicate an entire part to these conceptions because to those not familiar with the cognitive literature, the proposal of supra-individual cognition might sound fanciful. However, it is important to understand that supra-individual cognition is not as fantastic as it might initially sound. In fact, the notion that cognition pervades substrates other than the neural substrate (e.g. from inter-community or inter-personal networks) (Block 1978; Chalmers 1996) is related to the current established notion that cognition is a system incorporating the individual and the environment, called *extended mind* (Mithen 2001) or *externalism* (Clark and Chalmers 1998; Turvey and Carello 1995; Donald 1991). This part is an accumulation of research which I will later draw on as I take the first steps toward developing a comprehensive way of conceiving of cognition.

Chapter 2 charts the course of cognitive research, with special emphasis on *where* cognition resides. This chapter is important because it contains information that is pertinent to taking the first steps to viewing cognition in a more holistic manner. Though Chapter 2 may be redundant for those who have studied the history of psychology, it is critical for those unfamiliar with cognition and the debates surrounding it. For example, in this chapter, the idea that cognition is *computation* is explored, the implications of this idea being that cognition is *substrate independent* and that it can manifest itself outside the individual in the environment.

Chapter 3 revises the view, expounded at the end of Chapter 2, which is that cognition is computation. It examines the same fundamental questions as the first chapter only under a different paradigm called the *dynamical system*; that is, many cognitive scientists today regard cognition to be best understood as a dynamical system. A dynamical system is a series of functionally related components which acts through time and is commonly described mathematically by differential equations. It is argued in Chapter 3 that cognition is dynamical in nature rather than computational.

Part II

Part II of the thesis deals with the economic approach which I will utilize to describe Classic Maya exchange in the Maya Mountains. It also deals with the reconstruction and analysis of my case study of Bladen exchange. The economics discussed in this part of the thesis will be helpful in contributing to our understanding of cognition to be discussed in the third part of the thesis.

The archaeological case study that I will be examining constitutes an

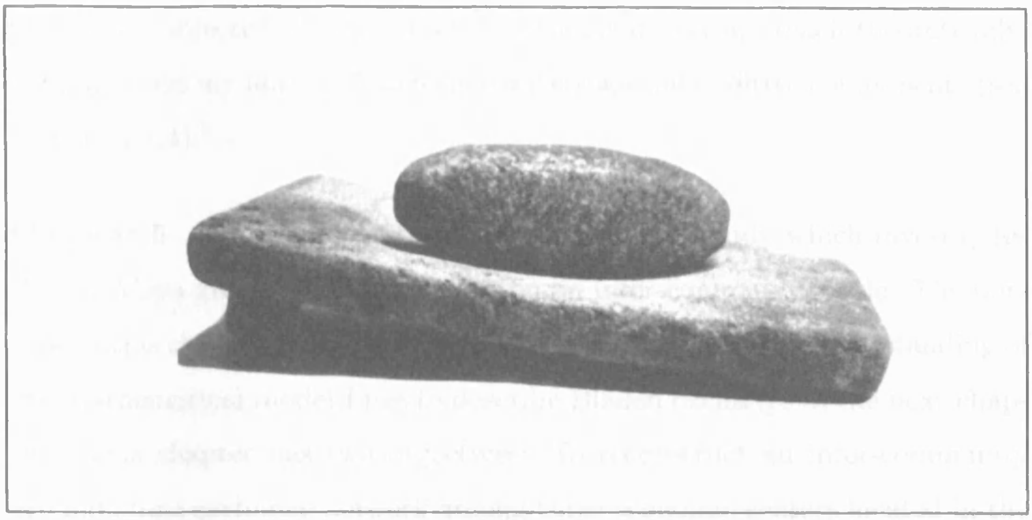

Figure 1: A mano and metate (photograph in Willey [1978]).

inter-community exchange system within the Bladen Branch of the southern Maya Mountains. Under the supervision of Dr. William Meurer, the project geologist for the MMAP, I have been able to reconstruct an exchange network of *manos* and *metates*. Manos and metates are ground stone grinding implements which were utilized to grind seeds and grains into flour, but more important, they were used extensively in ritual activities and for developing inter-household relations.

The data collected from this research will be used to construct a formal economic model of exchange, which will be analyzed mathematically to obtain information regarding the quantity of manos and metates per household at each of the Bladen communities. This model is then assessed with respect to ethnographic data.

Chapter 4 changes direction from cognition to economics. In this chapter the focus is on the economic approach that is taken to model inter-community exchange in the Bladen region of the Maya Mountains of southern Belize.

One of my objectives in this chapter is to situate my approach theoretically. I characterize my approach as formal with some substantive components (see Section 4.1.4).[2]

Chapter 5 is focused on the archaeological case study which investigates Classic Maya ground stone exchange on an inter-community scale. The purpose of this chapter is to describe the case study to facilitate understanding of the mathematical model I use to describe Bladen exchange in the next chapter. This chapter has two objectives: To reconstruct an inter-community ground stone exchange network among three economic centers located in the Bladen region of the Maya Mountains, and to investigate export of ground stone tools to centers outside of the Bladen region. Investigating export involves contrasting two exchange phenomena — one exchange phenomenon manifests itself among centers in a local context, and another manifests itself between regions. The data I use to investigate these phenomena have been obtained through sourcing manos and metates at several communities inside and outside of the Bladen region.

Chapter 6 focuses on demonstrating that my archaeological case study of exchange constitutes a credible dynamical system. In my case study, I investigate Classic Maya ground stone exchange among three economic centers, all of which are located in tributary valleys of the Bladen Branch in the southern Maya Mountains. Data are drawn from ethnographic, ethnohistoric, geological, and archaeological sources in order to reconstruct Bladen exchange, as well as to infer the significance of manos and metates in the Bladen region. A mathematical model is then constructed in order to de-

[2]For an in depth discussion of what constitutes a substantive economic model and what constitutes a formal economic model, refer to Sections 4.1.1 and 4.1.2.

scribe Bladen exchange. The mathematical model is based on supply and demand. This model is then assessed by comparing the output generated by the model with ethnographic data.

Part III

Part III synthesizes the research that was discussed in Part I regarding the nature and pervasiveness of cognition. I then turn to my archaeological case study and show that the dynamical system of ground stone exchange among the Bladen communities, which my mathematical model describes, further supports the pervasive view of cognition (i.e. its substrate independence), the conclusion being that there is cognition associated with the Bladen exchange system. This means that social institutions such as exchange can in a general sense be regarded as sources of cognition. The notion developed is that there is an abundance of such sources. However, if there exist multiple sources of cognition in this world, then a model must be conceived of which explains how it is that each of these sources of cognition affect each other. I propose the first steps in realizing such a model and discuss implications for social theoretical issues in archaeology.

Chapter 7 synthesizes the research discussed in Chapters 2 and 3. Chapter 7 demonstrates that the Bladen exchange system can be conceived of as a supra-individual cognitive process. What is discovered from the mathematical (i.e. functional) description of the Bladen exchange system as well as the nature of the actual exchange system is that it not only describes a dynamical system, but it describes a cognitive system. This would be consistent with current cognitive scientific research, which essentially defines a cognitive system to be a dynamical system to which an individual is attuned.

With regards to the Bladen exchange system, attunement to the exchange system gives the exchange system its cognitive character.

Chapter 8 follows through with Chapter 7's implications of what it means for exchange systems and other social institutions to be cognitive. If there exist cognitive systems other than the cognitive systems that occupy human nervous systems, then multiple sources of cognition exist. These independent sources of cognition, however, must affect each other in some manner, since the effects of cognitive systems can be felt on each other. An attempt is made at realizing a model that explains how cognitive systems interact while retaining their independence. The implications for social theoretical issues are also discussed to illustrate the explanatory power of such a model.

1.4 The Status of the Mind in Cognitive Anthropology and Archaeology and Its Implications for a Model of Cognition

In this chapter, I situate my thesis with regard to research that has been carried out in anthropology and archaeology on cognition. In general, cognitive studies in anthropology and archaeology are concerned with attempts to understand *what kinds of minds we have* or *what the mind is like* with the objective of obtaining a description of the mind. For example, the mind has been described using various metaphors from a "cathedral" (Mithen 1996:67) to a "structure-seeking device" (D'Andrade 1995:120). My objective on the other hand is to understand more fully the processes or underlying mechanics of the mind, an understanding to which archaeology can contribute.

Up to now, archaeology has contributed to an understanding of cognition largely through expanding our knowledge of the evolutionary record and suggesting how evolutionary processes have resulted in the modern mind of which the brain plays a central role. My thesis is oriented differently. Instead, I attempt to draw on the notion that the underlying mechanics of the mind can also be seen to underlie the social environment (i.e. the social institutions pervading a particular society) as well as the brain and that our understanding of cognition can be furthered through the study of social institutions in the archaeological record.

In the past decade, the evolutionary psychological model of cognition subscribed to by anthropologists such as Dan Sperber and archaeologists such as Steven Mithen, which can be seen to be a dominating view in cognitive anthropology and archaeology, comes as the result of expanding our knowledge of the evolutionary record. However, the data that have been collected by anthropologists and which have served this model can be interpreted in another way, which differs from the evolutionary psychological model of cognition. For this reason, and because the nature of the contribution from archaeology is at issue, it is important to discuss the contrasting approaches, how they stand in relation to each other, and how each of them can be seen to be upheld by cognitive anthropological research. Other information that supports a model of how the mind works, which this thesis is building toward, is drawn from research in the psychological, sociological, philosophical, mathematical, and engineering sciences, and I review these sources in the upcoming chapters.

1.4.1 Cognitive Capabilities and Representations

Cognitive anthropologists rely heavily on the notion of *cognitive capabilities* — such as perception, memory, and reasoning — to describe the mind.

The reason for this is that cognitive capabilities are really what cognitive anthropologists are talking about when they refer to mind. Thus, when cognitive anthropologists speak of the kind of mind we have, what they mean is more specifically the nature of our cognitive capabilities (e.g. how our cognitive capabilities are affected by external stimuli). Cognitive capabilities are investigated through *representations*. Representations can be seen in two ways. They can be seen as: 1.) *Concepts* which form in the minds individuals (e.g. ideas, beliefs, prototypes), or as 2.) *Ways* in which individuals utilize their cognitive capabilities — perceive, remember, reason (e.g. categories and schema). As *concepts*, representations can be seen as instances of the ways in which individuals utilize their cognitive capabilities (e.g. a prototype is an instance of a schema [D'Andrade 1995:179]). In this case, representations often can be elucidated by *what* human subjects report when they respond to a certain stimulus (e.g. a subject's answer in response to a question which can illuminate the concept the subject has in mind). As *ways* in which individuals utilize their cognitive capabilities, representations can be considered to be built on concepts (e.g. a schema is made up of concepts [Sperber 1996:67-70]). In this case, representations can be elucidated by *how* human subjects respond to certain stimuli, thereby uncovering the structure or order behind the subjects' thinking (Levi-Strauss 1963:33-34, 1978:11-12). In short, representations are concepts *in* the mind, whether they are built up from constituent concepts to form ways of thinking or are instances of these ways of thinking. Moreover, the kinds of representations on which people report tell the cognitive anthropologist much about what the mind is like (D'Andrade 1995:182).

On a more fundamental level, representations are two things: 1.) They are the products of cognitive processes or systems (van Gelder and Port

1995:11-12), 2.) And they are signs and thus are not only informational — representation is often synonymous with information — but are meaningful to the interpreter in question. With regard to this latter point, it makes sense that capacity for meaning is closely associated with the memory storage. Information stored in memory can be seen as being meaningful to the interpreter at some level, making this information a representation (Sperber 1996:74,78,80). As a result, a representation is characterized as being long-standing. Thus, there is some overlap between 1 and 2, since the storage of a representation into memory is the result of cognitive processes or information processing to be more specific.

If we look at anthropological work rooted in semiotics, much of which is based on Saussure's (1960) model of the sign, the instantiation of a representation begins supra-individually (e.g. Geertz 1973, Sahlins 1976). There is a stimulus external to the individual and there is an internal image of the stimulus which calls upon an internal signified concept. Thus, in Saussure's model of the sign we see four entities: an external stimulus, an internal signifier, an internal signified concept, and an interpreter (i.e. in this case the individual). Traditionally, the sign system is the system involving the last three entities, namely the internal signifier, the internally signified concept, and the interpreter; but some researchers have conflated the external stimulus with the internal signifier, making the external stimulus the signifier in the sign system (e.g. Sperber 1996:61). For others, the representation is the signifier, whereas for others still the representation is the signified concept, which is the *meaning* or more specifically the *signification* of the signifier. In another instance, for some researchers, it makes little difference which component of the sign is referred to as the representation, because signification is instantiation, which is to say that the signifier and the signified are instances of each other (i.e. one and the same).

The way I use the term representation should be clear by the context in which I use it. I generally take the view that the representation is the signified concept (i.e. the meaning of the signifier) and that signifier and signified are separate until explained otherwise. For example, I explain later in the chapter that signifier and signified can become associated, in effect becoming one, by considering signification to be a process — rather than an instantiation — in which a signifier is provided with meaning (i.e. a signified concept) and meaning is provided with a signifier. For the association between signifier and signified to manifest itself, it suffices to show that the signification process is capable of memory storage (as I alluded to above), since it is difficult to imagine how something in memory could not have meaning for an interpreter. When I use the phrase "how representations arise," I am generally concerned with precisely this process in which signifier and signified become one. This is to say that in this particular context, I conceive of the representation as the entire sign and as a process in which the signifier and signified become associated. I rarely use representation to refer to a signifier but when I do, I qualify it by calling it a "public representation," which is consistent with Sperber's (1996:61) usage.

When cognitive anthropologists investigate what the mind is like, they do so by treating representations as if they are signs (see point 2 above). They are not much concerned with the specifics of *how* these representations arise, since to explain what the mind is like, it suffices to say that representations exist *a priori* and that they are of a certain kind depending on the conditions that are determined by the controlled settings of the tests on subjects (e.g. having subjects from different cultures report on their perceptions, or having subjects recall representations after time lapses rather than having them report directly on their perceptions). The approach of assuming representations to be signs *a priori* can point us in the right direction for exploring explanations of how representations actually arise (i.e. the cognitive processes involved in the production of representations [see point 1 above]) which is the main concern of this thesis.[3]

As I mentioned above, the study of the cognitive processes or systems that generate representations in the mind — what I will be discussing in the chapters to come — is different from the study of the kinds of *a priori* representations we are assumed to have in our minds. Much of cognition concerns the processes by which representations are perceived, learned, stored, and recalled — which amounts to how they arise — as well as the executive control over these processes aimed to achieve certain tasks. Cognitive processes are commonly taken to be physiological (e.g. Johnson 1990) and or neurological (e.g. Sperber 1996), but the view taken here is that the material substrate in which cognitive processes operate need not be embodied. Representations, on the other hand, constitute the phenomena which cognition invokes and on which the subject being studied by the cognitive anthropologist can report. In most research, representations are usually considered to take the form of either images or language. The form of imagery or language enables the subject to report on the representations that are generated as the result of the processes involved in cognition. And it is because of the form that representations take that many aspects of the mind can be illuminated, simply from

[3]Simply assuming that representations are signs that appear through instantiation with no discussion of how the signs actually form is no explanation, and this lack of explanation has unfortunately guaranteed the impossibility of ever accessing the original signified concepts behind the signifiers. Thus, objectivists for the most part have given up the task entirely, leaving it to subjectivists — which is especially apparent in the schism between processual cognitive archaeology and interpretive archaeology.

what the subject verbally describes of his or her experiences. Whereas the representations of a subject may not be exactly what the subject reports, the representations are close enough and constitute what cognitive anthropologists and psychologists depend on to get some idea of what the subject is thinking about (i.e. an emic perspective).

Whereas the study of representations as signs is different from the study of the cognitive processes by which representations arise, the two studies generally have been regarded as being complementary since the time of McCulloch and Pitts (1943) who found that neurons, which can be conceived of as material *signifiers*, have information processing capability — a capability which can be seen to involve storing and retrieving *signified concepts* (see Section 2.2.1). Since the 1940s, cognitive research has gone a long way in demonstrating that there are cognitive processes at work dependent on neural dynamical systems that generate representations in the mind and which the individual in turn experiences and on which the individual can report (see Chapter 3). The complementarity of the study of representations as signs and the study of the cognitive processes by which representations arise is what enables clinical psychologists, for example, to work closely with neuroscientists. Although neuroscientists typically study cognition through the nervous system, and psychologists, the kinds of representations their subjects report on when exposed to certain stimuli, together psychologists and neuroscientists can shed important light on cognition and the mind as a whole.

Psychologists and neuroscientists study representations and cognition, respectively, under conditions which isolate the individual subject. Like psychologists, cognitive anthropologists also study representations, but they control for factors such as culture to understand how these factors impact an individual's representations. This makes the cognitive anthropologist the analog of the psychologist except that the settings are controlled differently. However, just as psychologists — who study the mind — work with neuroscientists — who study cognition — it is crucial that the cognitive anthropologist have a counterpart who is equipped to deal with the cognition which gives rise to representations. In short, the study of cognition and the study of representations constitute two ends of a continuum that represents human thought. Those who study representations on which subjects report approach the mind and its representations from one end and those who study cognition and how representations arise approach from another end. This notion of approaching the study of human thought from two directions holds the promise that some day these studies will meet and have the potential to explain human thought holistically. Neither those who study representations nor those who study cognition are equipped on their own to handle the task of illuminating human thought. In anthropology we have the cognitive anthropologists who for the most part study representations; what are needed now are anthropologists and archaeologists who study cognition via the processes by which the representations in the mind emerge.

1.4.2 Innate Versus Relative Cognitive Capabilities

There are two schools of thought on the subject of the kind of mind we have: evolutionary psychology, which focuses on the structure of the mind, and the relativist school. These schools occupy two theoretical extremes; however, the general consensus is that the way the mind works lies somewhere between the extremes.

Evolutionary Psychological View

Evolutionary psychologists propose that the mind at birth already contains certain kinds of information. Indeed, it is generally considered by the evolutionary psychologists that not only are representations innate (e.g. Chomsky [1957]), but the cognitive processing of these representations constitute innate, distinct, self-contained modules in the mind (Fodor 1983). How many representations and modules already exist when the individual is born and what kinds of knowledge these representations and modules reflect are still debated, but that representations and modules exist from birth is the hallmark of this school of thought.

Evolutionary psychologists envision the mind as a tool with several different functions. Mithen (1996) describes the mind as a Swiss-army knife, with each utensil serving a specific function. All of these functions were slowly acquired from the time our australopithecine ancestors branched off from chimpanzees five million years ago. In short, the different functions of the human mind evolved as adaptations to environmental features that our hominid ancestors experienced. These functions evolved so as to respond to dangers as quickly and as efficiently as possible. A general-purpose mind would have responded too slowly.

In evolutionary psychology, the mind does not differ significantly among individuals — at least not individuals of the same species. The species which comprised our lineage (i.e. *Australopithecus afarensis, Homo habilis, Homo erectus*) thought in a different manner than we *Homo sapiens* now do, but for the most part, our species sees things in very much the same way. As Renfrew (2001:30) has pointed out, more evidence points to the similarities of our species' thought processes than to its dissimilarities.

Evolutionary psychologists have assembled evidence from linguistic as well as psychological sources to support their claims (Chomsky 1957; Baars 1986:208; Fodor 1983). Chomsky (1957) showed that it was unlikely that humans could acquire language by learning the language in a stimulus-response fashion without some innate representations, which he termed a universal grammar hardwired from birth. Building upon Chomsky's work, Fodor (1983) claimed that not only do there seem to be innate representations built into the mind, but there seem to be embodied faculties or modules dedicated to the processing of these representations. These modules are components of the mind that would have come into existence with the individual's birth and would have been the product of millions of years of adaptation.

Fodor (1983) sees the mind as having a two-tired architecture in which there exists a central conceptual module and a layer of efficiently functioning perceptual modules. The conceptual module is a central general-purpose module that can access, conceptualize, and process its own information as well as information from the perceptual modules (i.e. input devices). According to Fodor there is a perceptual module associated with each of the senses and these modules are informationally encapsulated and are equipped with their own information processing capabilities; they cannot access each other nor can they access (to any significant degree) representations stored in the central conceptual processor. What this would mean, for example, is that what one sees is entirely unaffected by what one hears. Similarly, what general knowledge one has of the world one lives in should not affect to any significant degree the manner in which one perceives the world. This is a profound claim that can be regarded as the antithesis of the Sapir-Whorf Hypothesis, which proposes that our general cultural knowledge determines how we perceive things (Sapir 1921; Whorf 1956). Fodor (1983) proposes nearly the opposite — that general cultural knowledge, which would be stored in the central processor, has very little effect on the manner in which we perceive the world.

Cosmides and Tooby (Cosmides and Tooby 1992; Tooby and Cosmides 1992) emphasize the evolutionary aspect of modularity and in so doing propose that the general processor itself was divided into modules. They claim that because the mind is a product of biological evolution, vestiges will remain of the processing subsystems that our hominid ancestors needed to survive at various times in the past. Fodor's (1983:101-119) general processor, which can be termed a conceptual module since it deals with concepts rather than percepts (Sperber 1996:120-121), would have encountered errors as well as successes due to the growing number of tasks that early humans would have needed to face. Therefore, Cosmides and Tooby propose the existence of innate processors designed specifically to solve problems that a hunter-gatherer would have faced within the past 70,000 years. Just as Chomsky argues that it is impossible for language to be acquired without innate information in the form of grammar, so too do Cosmides and Tooby argue that human beings need some innate conceptual processing to deal with problems faced in life. According to the evolutionary psychologists, early humans needed to have self-contained modules with their own information processing functions and some *a priori* representations to be able to deal with unpredictable as well as rapidly occurring events in the Pleistocene. The research of Cosmides and Tooby resulted in the proposal of multitudes of modules teeming with their own representations.

Enter Culture

Although the term "culture" is a variable one, in general it is used by cognitive anthropologists (e.g. Leach 1976, D'Andrade 1995, Sperber 1996) to refer to representations which we as a social group construct in our minds and which affect our intra-individual cognitive processes (D'Andrade 1995:146). Although representations are formed in the mind as signified concepts, they have material counterparts outside of the individual which instantiate the concepts. As I discussed above, some semioticians conflate Saussure's (1960) internal signifier with the external stimulus. It is precisely this conflation which, in search for a structuralist explanation of culture, has contributed to anthropologists' and archaeologists' attraction to Saussure's theory of signs in the first place. Another view of cognitive anthropologists, called the cultural epidemiological view (Sperber 1996), sees culture as structuralists do, but with additions (discussed below).

Envisioning culture as a representation — or sign — has made it possible to explain culture in a concise manner. The conceptualization of culture as a representation gives form to culture. Culture in the representational view can be defined as stimulatory information (normally taken to be outside of the body) that structures the mind and in so doing makes the mind that is structured part of culture too. While this definition does not explain what culture is but rather what it does (i.e. it is a functional definition), anthropologists and archaeologists would generally regard it as an improvement on seeing culture only as something shared. The representational view grants culture an *active* role, whereas the traditional definition grants culture a *passive* role. In a sense, the representational view escapes having to define what culture is by providing it with a job.

Culture, then, like all representations, can be conceived of as: 1.) All of the human-made things outside of the mind that structure cognition. An example is material culture or the phonetic component of language (e.g. the sounds, or more specifically the pronunciation, of words, as well as the words on a page). 2.) All of the things inside of the mind that these external things have structured. An example is the signified concepts in the mind that are being instantiated (e.g. the meanings of certain objects in our material culture or the phonemic component of language or how something is heard and interpreted).

In practice, very few people write in a way in which culture constitutes a whole representation (e.g. Saussure's sign) even though they may mean to. In general, cognitive anthropologists refer to the concepts in people's minds as culture (e.g. D'Andrade 1995). Archaeologists, on the other hand, refer to the signifiers as culture, or as material culture, even though much more than signifiers is implied by the term representation.

Relativist View

The relativist school of thought, also called the Standard Social Science Model, sees the mind as a blank slate and everything which constitutes the mind is learned after birth directly from the environment (Tooby and Cosmides 1992). The environment can be cultural, social, or natural. Even though most work in cognitive anthropology concerns the effects of cultural environment on the mind, one just as well could consider the mind to be shaped by elements in the natural environment.

At birth we are provided with a tool to process this information coming from the outside which we call the brain. The brain can be seen as a computer running a general purpose program that enables the individual to learn, compare, and contrast information, but there is little predisposition for learning some kinds of information over other kinds of information, nor is there any *a priori* cognitive representations that an individual is endowed with at birth.

In the relativist view, the mind works much like a computer in that the hardware — in our case the brain and its neural substrate — is the only aspect of the mind that we have at birth. The software and the data we use in processing (i.e. the representations) come from the environment as we develop. We enter various social institutions, such as schools, and we learn in a particular manner about particular things. An information base is established and it is this information base that constitutes the representations we envision and which we use to view the world and interact with other individuals.

The logical consequence of such a view of representations is that people in different social or natural environments will be presented with different representations and hence will conceptualize differently. These concepts are the result of the mind being subjected to different associated representations. This is an environmentally deterministic view of the mind, but one can see how it makes sense if one accepts that our bodies contribute little beyond manipulating and processing representations which are provided via the environment.

The notion that the social environment shapes our processing of representations was formalized in the Sapir-Whorf Hypothesis (Sapir 1921; Whorf 1956). Sapir and Whorf were linguists who proposed that features of the environment, specifically language, construct the world we perceive and know. For example, a person born into a culture with a language that did not have certain color terms would have a problem in differentiating these colors when presented with them. This is a profound idea, for it follows that the symbolic systems we humans construct, whether these symbolic systems are languages or whether they are the artifacts of our material culture, determine our conceptual reality. To put it another way, in the semiotic debate of what comes first, the signifier or the signified, this would suggest — counter-intuitively for many — that the signifiers come first and effect the signified concepts. Could it be that the external stimuli and their associated signifiers determine the concepts we experience? And if so — if culture as signifier does have such a power over human conceptualizing — how can anthropologists ever hope to understand the people they study? Archaeologists following the post-processual track accepted this notion of culture as a range of signifiers (e.g. Hodder 1982 and Tilley 1989) and they referred to the study of how the material objects form conceptual reality as symbolic or structural archaeology.

The relativist position can be taken further than *cultural* relativism. Because relativists believe that our interaction with the environment shapes how we think, then it is reasonable to conclude that each individual thinks uniquely. This notion is not new, but has pervaded philosophical thinking from the time of Rene Descartes and Johann Fichte (see Chapter 2). It is based on the belief that we see things through our own "mind's eye," and each person sees things differently, which can mean that there is no objective existence beyond our minds — no reality, no truth — except for what we can agree is there.

Modifying the Relativist and Evolutionary Psychological Views

Both the relativist and evolutionary psychological stances have modified their views over the past ten years, and it seems that most researchers have come to accept certain views from both schools of thought.

In contemporary research, most cultural relativists generally agree that there is an interactive and persistent relationship between the material signifiers we construct and the associated concepts in our minds. That is, signifiers construct our concepts, but our concepts can modify, eliminate, or give rise to signifiers. Interpreted in this way, the question of what comes first — the signifier or the signified — is no longer a worthwhile enterprise, since the two aspects of the sign can be seen to be part of a feedback system for which there is no prior or posterior event, but rather a simultaneity of events in which signifiers are conjuring up signified concepts and signified concepts are causing via action the construction of signifiers. Functioning as a feedback loop eliminates any order of happenings since signification and sign construction are for all intents and purposes occurring simultaneously. This systemic paradigm eliminates the need to discover a cause, which in any case could lie either with the signifier or the signified. Hodder (1986:12-14,48) and Barrett (1994) are good examples of the tendency to modify the proposal that culture determines our cognitive processing.

Research into the innateness of mind — that began with the work of Chomsky (1957) and culminated in the research of Tooby and Cosmides (1992) — is similarly regarded to be extreme. A reaction to this extremism has caused some advocates of evolutionary psychology to accept the influence of cultural context on a child's development (Karmiloff-Smith 1992). Other advocates of evolutionary psychology (e.g. Sperber 1994 and Mithen 1996) have reacted by simply narrowing down the number of innate modules proposed by Tooby and Cosmides (1992:113) to only a few. Even Fodor (1987:27) commented that one could take the modularity argument too far to the extent that everything we do and think about is biologically conditioned and hence genetically determined. Recently, researchers in the realm of evolutionary psychology have been taking Fodor's warning into consideration and have been toning down hard-wiring arguments to include fewer modules. For example, Mithen (1996), drawing on the work of Whiten (1991), Atran (1990), Karmiloff-Smith (1992), and Sperber (1994), has proposed five modules, namely a technical intelligence, linguistic intelligence, social intelligence, a natural history intelligence, and a general intelligence module. Sperber's (1994) model of the mind is similar to Mithen's model with the exception that Sperber emphasizes a module of meta-representation, a location where one can generate higher-order thought processes (i.e. the capability of forming complex representations built on simpler representations).

Modifications to the cultural relativist stance and to the biological determinist/ evolutionary stance coincide with rigorous attempts at testing the Sapir-Whorf hypothesis by cognitive anthropologists. The strength of the Sapir-Whorf hypothesis has been tested on different cognitive capabilities, namely perception, memory, and reasoning (D'Andrade 1995:182-207). The results of these test show that culture has some influence over cognitive capabilities but not to the extent which relativists argue. The impact that culture has on the mind depends on the situation or context in which the subject finds himself or herself. As such, it turns out that the mind in some instances appears to be operating almost entirely as if it was innate, which is the case with perception and episodic memory, as Rosch's (1972, 1973) and Berlin and Kay's (1969) studies show. In other instances, it is as if the mind was culturally determined, as is the case with semantic memory and reasoning. Hamilton and Fagot's (1988) research shows that one's biology does not necessarily explain (long-term) semantic memory. Nor does biology explain the studies on reasoning conducted by Wason (1968), Johnson-Laird, Legrenzi, and Legrenzi (1972), Cox and Griggs (1982), and Cheng and Holyoak (1985).

Environment and Mind: The Situation as It Stands

As can be deduced from the cognitive anthropological studies discussed above, there is no getting away from the fact that environment is responsible, in part, for how we utilize our cognitive capabilities, especially with regards to semantic memory and reasoning. The question is: "How does the environment affect our cognitive capabilities?". The traditional structuralist view held among relativists is that signifiers in the environment invoke particular representations in our minds (see pages 23–25). In this view, the mind is effectively a receiver for representations that are contained in the environment. However, in light of the work conducted by other researchers, the mind is considered to be innate in certain respects (pages 19–21 and pages 25–27), which is to say that mind is not only a receiver for representations, but it also contains the representations and the cognitive capabilities that are responsible for the production and manipulation of the representations.

1.4.3 Explaining How Environment Affects Cognitive Capabilities and How Cultural Representations Are Formed

One explanation that can be seen to incorporate both evolutionary psychological and relativist aspects of the mind, focusing primarily on the effects of the cultural environment on basic cognitive capabilities, is called *cultural epidemiology*. Cultural epidemiology can be seen as being based on structuralism, which Sperber (1996) complements with the notion of innate mental modules.

Brief descriptions of structuralism and Sperber's view favoring an innate mind are provided below so that the reader can better understand how relativism and evolutionary psychology can be intertwined to produce a coherent model. The cultural epidemiological model can be compared and contrasted with an alternative model I propose later in the thesis concerning how cultural representations or, what I prefer to call, *social representations* form. Sperber's cultural epidemiological model explains how cultural representations can manifest themselves as well as remain in the individual's mind.

Structuralism as an Explanation of How Representations Arise in the Mind

Representations are instantiated in the mind of an individual through signification prompted by an external stimulus in the environment. Referred to as *structuralism*, the notion of representational instantiation has its roots in semiotics, in particular in the notion of the primacy of the signifier, where representations are considered to be signs which are transmittable through communication. For example, a mental representation conceived of by an individual can be externalized in the form of a public representation, such as the sound of a word. The sound of this word then functions as an external (phonetic) stimulus to an internal (phonemic) signifier of the word, which in turn signifies a meaningful (morphemic) concept in the mind of an interpreter.

Structuralism by itself, however, is inadequate in explaining how cultural representations form because it logically entails an extreme relativist view of the mind, which as I discussed in pages 19–21 and pages 25–27, does not entirely describe the human mind. How structuralists propose that the environment invokes cultural representations in the mind of the individual is discussed in pages 21–27.

Sperber's Explanation of How Representations Remain in the Mind

When instantiated, the representations which have manifested themselves in the human mind are transformed into (long-standing) cultural representations through embodied cognitive processes. This is accomplished through the ability of innate mental modules to attract specific kinds of public representations, enabling the public representations to carve out domains for themselves.

Modules harbor naïve ways of conceptualizing certain aspects of the natural world and are equipped with their own memory stores and hardwired processing capacities. Some proposed modules are: a naïve physics module, a naïve biology module, and a naïve psychology module. Each of these modules evolved as the result of our adaptation to the environment early in the prehistory of our species and each module is self-sufficient in accomplishing a task. Depending on whether the content of the public representation articulates with the content of an established module, a public representation can parasitize a module that has taken thousands of years to evolve, thereby carving out a domain for itself within the module. As a result, a public representation which has carved out a domain for itself can graduate to a cultural representation, and the domain occupied by the representation within the module is transformed into a cultural domain (Sperber 1996:135).

It should be pointed out that a public representation which first makes it into the body from the environment may or may not become a cultural representation, but the point is that the mechanisms responsible for transforming a representation in the environment into a cultural representation are embodied. Although it has been implied by some research supporting an innate mind (e.g. Fodor 1983) that embodied cognitive processes are somehow responsible for the formation of cultural representations (Nugent

1985), no rigorous explanation was put forward until Sperber's (1996) formulation. Sperber incorporates aspects of structuralism (above) and evolutionary psychology (pages 19–21) into a model that accounts for how cultural representations not only arise, but how they are *stored*.

1.4.4 Problems with Structuralism and Cultural Epidemiology

Both cultural epidemiology and structuralism offer explanations to account for how concepts that the relativists would claim to be culturally induced arise in the mind. The difference is that cultural epidemiology is seen by many to be an improvement over structuralism since it not only depends on certain structuralist principles but it incorporates the notion of mental modules which many take to be a scientifically grounded notion. However, there are problems with both structuralism and the modular hypothesis. For structuralism, the problem is the fact that it relies on the notion of signification as an explanation for how meaning arises. However signification, as defined by Saussure (1960), is instantiation and instantiation is not an explanation. The reason instantiation is not an explanation is that it cannot be verified, and this makes signification an untestable hypothesis and an untestable hypothesis is as good as no hypothesis. Cultural epidemiology faces a problem regarding its explanation of how representations persist, a key feature of what constitutes a "cultural" representation. Cultural epidemiologists hypothesize that representations become long-standing through an inherent attraction of certain kinds of representations to certain innate modules. The problem is that there is little evidence to suggest that embodied modules have independent storage capacities to deal with specific kinds of representations while excluding other kinds of representations.

Problems with Structuralism

Structuralism has shortcomings which make it inadequate as an explanation of how cultural representations arise, and which also impair the cultural epidemiological model. The main problem with structuralism is that what makes it work in structuring concepts in the mind cannot be examined in detail, and this applies also to many semiotic-based arguments.

Structuralism has failed as an explanation on a number of points from an empirical perspective. Structuralism cannot be tested, since it explains the mind as an instantiation of a sign; one component of the sign is a material signifier in the form of an external stimulus (e.g. an object) or internal signifier (e.g. activated neurons) and the other component of the sign is the signified concept detained in the recesses of the mind. However, instantiations are not adequate explanations since there will never be evidence for how something instantiates — it just *does*. This probably stems from the fact that time is completely neglected as a factor. Time, however, is essential whenever one is concerned with understanding how something goes from Point A to Point B (i.e. from signifier it signified or vice versa). Without incorporating time in one's analysis, one can only say that at one instant something is at Point A and then it is at Point B. What is needed is a set of intermediary points or a set of rules which describe how something moves along a path from Point A to Point B, and this means that time must be involved. Simply conceiving of meaningful (signified) concepts as being instantiations via association with a signifier does not constitute an explanation. Instantiation is not an explanation that can be tested. It is a metaphor of how a signifier can has the capability of generating an associated signified concept in the mind. Therefore, it is a kind of explanation in that it sets a viable stage or frame for investigation. But more is needed to engage with the details of an instantiation process.

Another problem with structuralism is its claim that material culture is a sign system. While there has been much discussion that material culture does indeed constitute a sign system, there is no general agreement on how such a sign system works. As such structuralist approaches to material culture seem to have gone through two phases, which can best be described as syntactic and interpretive approaches.

The first phase was taken by Hodder (1982) and it amounted to envisioning the archaeological record as a text, in which each artifact grouping consisted of a sign, not unlike a word in a text. By considering each artifact grouping with respect to another the hope was that some meaning or associative rules regarding different artifact types could be extracted from the archaeological record, just as a linguist might approach a text written in an ancient language in order to ascertain the syntax of the language. In this way, arriving at the meaning of a certain distribution of artifacts was reduced to ascertaining the "syntax" of the archaeological record.

There are problems with the syntactic approach. The main one is that the archaeological record is not a unified text that is written to reflect meaning (Renfrew 2001:22), especially if we consider all of the unintentional actions that go into site formation processes which result in the archaeological record. But even if we accept that the archaeological record is meaningfully constituted, then as linguists know, ascertaining the *syntax* of a language is only part of the process of extracting meaning from texts. This is because a syntactic analysis essentially amounts to illuminating the grammar of the language in which the text, or in our case the archaeological record, is written. The problem with the syntactic approach is not only Renfrew's poignant observation that the archaeological record is not a text but that syntactic meaning or *value* is not really the kind of meaning that concerns archaeologists. Most archaeologists want to know what the material objects meant to the people they are studying or how these material objects were used symbolically, not how artifact groupings disconnected from people are associated in some abstract language of the archaeological record.

The most problematic aspect of the archaeological record's uncertain status as a text is that the record can only be accepted at face value, with no explanation as to how the meaning of material objects being studied arose in the first place. As such, the syntactic approach, in which the meaning of material objects in the archaeological record is supposed to be divined from analogical chains (see Hodder 1982), can be seen as a method blatantly detached from the people who actually gave the objects their meaning (Hodder 1986:49). In this way, the meaning which can be arrived at by using the syntactic approach does not seem to be the kind of meaning that would be of any consequence to an archaeologist.

The realization that the syntactic approach is problematic was not the end of material culture as a sign system. The kind of meaning that many archaeologists appeared to be interested in was the *semantic* meaning of the artifacts in the archaeological record. That is, archaeologists wanted to know what the artifacts in the archaeological record *signified* to the people that were being studied. Structural analyses seemed to be reduced to advocating the primacy of the material cultural environment over representations in people's minds (e.g. Tilley 1989). The point of these analyses was simply to say that if material culture does generate associated concepts in people's minds then archaeologists and anthropologists alike should be able to grasp the concepts of the people being studied by studying their material culture.

The question which still remained, however, was *how* were artifacts to be studied so as to reveal *what* their associated signified concepts were. For many, this question was avoided; the answer for these archaeologists who avoided the question was to claim simply that there are no objective methods for understanding how one arrives at concepts in people's minds from their artifacts. The view of these advocates, which represents the phase that came after the syntax phase, is currently held by the interpretive archaeologists (e.g Thomas 2000) who advocate a subjective view of the archaeological record. Their idea is that because the archaeological record is a text and because a text is read and interpreted subjectively, the reader of the archaeological record can interpret the record. This means that the archaeologist can arrive at the semantic meaning of individual objects in the archaeological record and that all interpretations can be considered to be plausible interpretations.

The major problem with the interpretive approach is that like the syntactic approach, it retains the notion of the archaeological record as a text (even though it may focus more on the nature of the signs themselves rather than the text as a whole). As text, the material objects remain detached from the people who are supposed to be connected to these objects, and this is done by separating the material objects from the meaningfully enriched behavior that produced or distributed the objects in the archaeological record. A solution to this dilemma which I propose below is to consider the behavior or actions that produced and/ or distributed the material objects to be the sign systems rather than material objects themselves. An example of how meaning can arise from behavioral processes is how the meaning of money arises in contemporary western society. Money has no intrinsic meaning in itself; it is just paper or metal. What can be seen to give money meaning is the capitalist system — a social system and our behaviors that constitute it — in which we utilize and circulate the money.

The Problem with Cultural Epidemiology and the Notion of Modules

The cultural epidemiological model relies on the premise that because cognitive processes are embodied and because cultural representations constitute the output of these cognitive processes, cultural representations themselves are embodied. Depending on whether the content of a representation articulates well with the content of a specific module, the cultural representation (or mental representation for that matter) may be externalized in the form of a public representation (i.e. discourse), which can then carve out a domain for itself within an innate module. This process then begins all over again until everyone in the population being considered has this long-standing representation. This is the method by which cultural representations come to manifest themselves in peoples' minds and remain in peoples' minds according to Sperber (1996). The main point I want to highlight about cultural epidemiology is that even though the cultural representations are at some time or another disembodied public representations — depending of course on whether or not they are being communicated — the cultural epidemiological view depends on embodied cognitive processes to generate the cultural representations. The mind is taken to be embodied (Sperber 1996:120), which is to say that mental modules and the processes involved in making representations long-standing (i.e. cultural) are internal. However, the idea that cognition is embodied and that everything we conceptualize in the world has to be channeled into the embodied mind at some point or another is problematic, as I point out below. Luckily, however, the cultural epidemiological model is only one interpretation of the cognitive anthropological evidence.

Evidence for Perceptual/Conceptual Information Processing Sperber's cultural epidemiology theory, while it has many useful insights into how an innate mind with its modules can generate culture, has certain shortcomings. We learned from empirical evidence synthesized by D'Andrade (1995), which I recapped above, that semantic memory storage and reasoning are different from perception and episodic memory storage in that semantic memory storage and reasoning are heavily affected by the cultural concepts we construct whereas perception and episodic memory storage are not. What this suggests is a very different way of viewing the mind than that advocated by the evolutionary psychologists and hence the cultural epidemiologists who advocate domain-specific conceptual modules.

By domain-specificity, what is meant is that modules are self-contained units with their own memory stores and information processing capacities dedicated to specific tasks. Modules are autonomous by virtue of their ability to process information (i.e. store and recall representations) on their own, yet surprisingly little research looks at how the conceptual modules process information and whether or not there are differences in the ways the conceptual modules being proposed are storing and recalling representations — for example, whether the rates of storage and recall are different between two modules. If we focus on how information is processed in more detail, then the divisions which the empirical evidence supports are not between different self-sustaining conceptual modules but rather are more pronounced between information processing associated with perceptual tasks and information processing associated with conceptual tasks.

To take memory storage as an example, there is significantly more evidence to suggest that there is a difference between how memory works in recalling information relating to "ego" (episodic memory) and recalling social information (semantic memory) than there is a difference between how, for example, memory works in recalling animals using a naïve biology store and how memory works in recalling cultural information using a meta-representation store. According to Tulving (1983), representations stored in episodic memory take longer to recall than representations stored in semantic memory, and comparing and contrasting rates at which representations are stored and recalled can tell us something about how information is processed and whether it is accurate to claim that the information is being processed by autonomous processing units or modules. Using this line of reasoning, representations such as "pitbulls can be very dangerous dogs" and "one can catch a cold in the rain" according to the modularists should have different memory stores and very likely different ways of recalling this information. The information pertaining to pitbulls should belong to the naïve biology memory store whereas the information regarding catching a cold is very likely culturally specific information belonging to the meta-representation memory store. Yet, from what can be inferred from studies conducted by Tulving (1983), both of these bits of information are more alike than not alike; that is, both of these bits of information constitute social information, the content of semantic memory.

This seems to agree with at least one point that Fodor (1983) made in his modular hypothesis — that there is a distinction between the manner in which percepts enter the mind from the environment and are processed, and the manner in which concepts are processed. Perception can be conceived of as a process which connects the environment to ego, and episodic memory can be conceived of as the storage of representations regarding how things in the environment are related to ego. In this way, it would seem that Fodor's perceptual modules account for the informational inputs connecting ego with his or her environment along with the storage and recall of this information. Here, the storage and recall of information can be seen to be coextensive with the information processing associated with episodic memory and perceptual representation memory. Similarly, Fodor's central processor, which has the job of processing concepts, can be seen to be coextensive with the information processing involved with semantic memory. Though Fodor seems to agree with Tulving's (1983) and Nyberg and Tulving's (1996) research on this one point, the problem arises when the episodic and semantic information processing centers are partitioned even further as Fodor (1983) and the conceptual modularists (i.e. evolutionary psychologists and cultural epidemiologists) would have us do.

Lack of Evidence for Embodied Conceptual Modules As yet there is little evidence to suggest that specific kinds of social representations have their own conceptual information processing modules and associated memory stores which process them. Since Tulving's (1983) work, Nyberg and Tulving (1996) have identified what they find to be two other long-term memory systems, namely procedural and perceptual representation memory systems. What they have found is that each memory system of the four that they have identified is functionally distinctive, rather than task distinctive. That is, the memory systems which have been identified "contribute differentially to the *performance* of different tasks" (1996:164), not to the *content* of different tasks. The notion that there is a one-to-one mapping of tasks to memory systems — which is essentially what the modularists are saying — would be difficult to support (Toth, Reingold, and Jacoby 1994).

If conceptual modules are anything, they may be regarded as sectors of the mind with innate representations and innate implicational structures of these representations, which differ from one another in the way that they associate representations with other representations during memory storage and recall. However, this is a far cry from saying that these representations are being processed autonomously and only have access to their own stores. Even Mithen (1996:209-211) has to admit that modern *Homo sapiens* maintains a cognitively fluid mind in which information flows freely among modules. In what sense, then, can one say that the modern *Homo sapiens* mind is modular? Perhaps early in the evolution of hominids modularity played an important role in information processing, but it does not seem to play that same role now.

Not only does the notion of the embodied module stand in contrast to research on memory (Tulving 1983; Toth, Reingold, and Jacoby 1994; Nyberg and Tulving 1996) as I have discussed above, but the modular hypothesis also stands in contrast to research on *reciprocal casusality*, which PET and fMRI imagery data support (see van Orden and Paap 1996). Reciprocal causality is the notion that every component of the system — in this case the brain — contributes to every behavior of the system as a whole. An example of a study supporting reciprocal causality is Poeppel (1996), who conducted five PET studies in which no particular region in the brain could be consistently identified as the phonetic/phonological processing center of the brain. Examinations of impaired versus non-impaired subjects, in which impaired subjects were found to have problems with traditionally held task-specific regions in the brain, revealed that impaired subjects could compensate by using other regions of the brain. These experiments clearly stand in contrast with a model of the mind — taken to be coextensive with the brain — consisting of autonomous modules designated for specific tasks, as hypothesized by Fodor (Eaton 2000).

1.4.5 Moving Beyond an Embodied Cognitive Explanation

The explanation by which cultural representations become long-standing (i.e. stored in memory) through cultural epidemiology is based on one main premise. The basic premise explaining how cultural representations arise is that representations are content rich and it is because the content of the representations is compatible with the functions which embodied modules serve that the representation is attracted to a particular module and is permitted to be stored in the module's memory store. As I have shown, however, the view that each module has its own memory store isolated from the other modules is not demonstrated by the evidence, which instead suggests a shared memory store -- episodic memory for perceptual information connecting ego with the environment and, of prime concern here, semantic memory for general information such as social or cultural representations.

If we are to accept Tulving's and other's research on memory, some changes must be made to the underlying mechanism by which representations get stored. In the modular hypothesis, the mechanism for storing the representation lies with the content of the representation and how well the content fits into an appropriate module. However, if we accept Tulving's and other's research on memory, then the content of the representation and its attractiveness to an embodied module cannot be considered to be the mechanism responsible for the representation's storage and long-standing attributes. The notion that representations are content rich need not be eliminated, but the involvement of content in enabling the storage of representations in a module needs to be reevaluated.

This leads me to propose a different mechanism for the storage of cultural representations, or what I prefer to call *social representations*, to account for their long-standing character. This mechanism can be explained indirectly through cognitive anthropological research supporting the notion that the mind need not be embodied — at least not in its entirety. The first source comes from Gibson (1966, 1979) and the second source comes from Rosch (1972, 1973, 1978), Berlin and Kay (1969), and Dougherty (1978). Their work suggests that many of our representations of things are fully formed before they are even sensed. If we take this point together with what I stated earlier about the fact that representations are the products of cognition — the sense here being that representations constitute the information being processed — then what this implies is that the cognitive processes from which the representations arise must also be occurring outside of the individual.

Ecological Psychology and the Role of the Environment as a Source of Cognition

Ecological psychology is a rapidly growing field (e.g. Turvey and Carello 1994). A major proponent and developer of ecological psychology is James J. Gibson. Gibson (1966, 1979) proposed a theory in which representations which appear to us in the mind as images are extracted more or less *directly* from the environment (i.e. what we see is what we get). In this theory, very little intermediary processing is done between the raw data in the environment being perceived and their associated mental sensations (by the brain or the body of the individual). As such, the Gibsonian model of the mind can be conceived of as an extreme objectivist view of the mind. This idea that there are categories or, more generally, representations that exist in the environment which do not require much intermediary involvement from the body is referred to as the *objective mind* stance — which can be seen to stand in opposition to the *embodied mind* stance, though it does not stand in direct opposition to it since it does permit the individual body a role in generating representations in the mind of the individual.

Gibson's theory, which is primarily based on visual perception, extends to the other senses of perception, generally referred to as perceptual systems. Gibson sees the environment as a sampling space for the individual. In this view, the individual travels through time and space attuning to only the invariant information provided by the environment. At the same time, the individual can be conceived of as being part of the environment which he or she samples. Such a model of how the mind works can neither be situated in a mentalist view of the mind nor can it be considered to be a behaviorist view of the mind. Mentalism, which is a Cartesian view of the mind and a top-down information processing view, claims that perceptions are our own creations which are produced intra-bodily. Behaviorism (i.e. the strongest kind) which is a bottom-up information processing approach, on the other hand, claims that human minds are simply responders to external stimuli in the environment. However, ecological psychology, though it is often considered to be a bottom-up information processing approach, is not as extreme as behaviorism since it does not neglect the effects of intra-bodily processing on perception (Gibson 1966:264-65). In fact the body serves a role in perception, the role being attunement to the invariant information in the natural or cultural environment. It can be inferred from Gibson that he sees the environment as the "cognitive" source where most of the processing occurs, and that the body as a receiver homes in on the invariance in the environment. A good example of how he views the environment can be indirectly inferred through his description of cultural representations, which he takes to be information that has already being processed by the cultural environment before it is actually perceived and processed again by the individual (Gibson

1966:28).

Although there are problems with some of Gibson's assumptions, an important component of his approach is that the individual can be seen to constitute part of the environment — the individual is locked in a feed-back relationship with the environment, and is therefore part of the entire cognitive process which subsumes both participant and environment. To ecological psychologists, the mind is coextensive with the environment, such that mind and environment (including the individual) can be considered to be one and the same. This approach is similar to what the embodied mind advocates, inspired by Merleau-Ponty (1962) (e.g. Johnson 1990, Lakoff and Johnson 1999) are trying to accomplish; however, instead of placing the interface between the phenomenological realm and the material realm at the bodily extremities, the interface is being placed by the ecological psychologists at the furthest limits of human perception. This view clearly holds that the mind subsumes *both* individual and the perceptible (i.e. local) environment.

The view that the mind is coextensive with the environment and the perceiver, however misleading, should not be regarded to be an idealist view of the mind. Being coextensive with the environment attributes to the mind the same properties attributed to the environment and subjects the mind to the same rules or laws as those which govern phenomena in the physical environment. In fact, one of Gibson's major contributions is that in creating his model of the mind he created an interdisciplinary arena in which the laws of physics generally used to explain environmental events are equally valid for illuminating the mind. It follows from this that Gibson and his followers generally regard the mind to be material just like the environment outside of the individual. The embodied mind view does precisely the same thing when it places the body in the mind — it makes the mind material by coextending it with physiology (Johnson 1990). The major difference is that instead of putting the body in the mind, like embodied mind advocates do, the ecological psychologists place the environment in the mind.

Gibson's cognitive model is based mainly on his observation of human perception. However, his theory is clear. Gibson proposes that the environment constitutes the cognitive source, whereas the human perceptual systems are simply systems that can attune to the environment. Being attuned to the environment allows the individual to become part of the environment. In this manner, the mind is the product of an interactive and dynamic system between the individual and the individual's environment.

Cognitive Anthropological Support for the Environment as a Source of Cognition

Rosch's (1972, 1973) work on prototypes is quite well known, and her explanation of how things are more prototypical than other types in the same category is important for this discussion since it supports the notion that representations are formed in the environment before they reach the senses. This notion is related to the Gibsonian view of the mind which I discussed above.

Rosch's (1972, 1973) work on the Dani, a highland people in New Guinea, was concerned with color. Her observations showed that even though the Dani only had two color categories, the Dani best remembered the focal colors which were first proposed by Berlin and Kay (1969). Many would regard this as further support for an innate or embodied view, but Rosch's (1972, 1973) interpretation of these studies is different. Rosch's observations of folk taxonomies led her to propose that the focal colors represented basic level psychological objects just as certain animals and plants represented basic level psychological objects in folk taxonomies. In other words, people probably do not perceive and recall from memory the componential characteristics of a color or animal and build their way up to the color or animal, but seem to perceive and remember certain colors and animals in their entirety as gestalts. Thus, the gestalts of things in the environment form actual psychological objects, not the constituent features that may characterize the things in the environment. She based this on the premises that: 1.) people try to get the most amount of information out of the environment for the least amount of cognitive effort, and that 2.) the environment consists of structured information and therefore information being sensed by an individual is nether random nor uniform. That is, there are features which naturally co-occur in the environment that our senses lock onto and form into psychological objects, which are optimal in terms of the information that they contain. These optimal psychological objects are referred to as prototypes. Rosch (1972, 1973), synthesizing her work along with Berlin and Kay's (1969), suggested that focal colors and basic level terms in taxonomies are prototypes since they are the most informationally useful. They encapsulate more attributes than any other categories.

To demonstrate this, Rosch (1978) tested American respondents on several taxonomies across three levels by asking the respondents to list all of the attributes that came to mind for all of the levels for each taxonomy. The *taxonomies* numbered nine and ranged from trees to furniture. The *levels* consisted of superordinate categories, basic level categories, and subordinate categories. FURNITURE, for example, constituted one taxonomy as well as a superordinate category. A basic level category of FURNITURE was CHAIR, and a subordinate category of CHAIR was LIVING ROOM CHAIR. What Rosch's tests demonstrated was that very few attributes were listed for FUR-

NITURE, significantly more for CHAIR, and not many more attributes were listed for LIVING ROOM CHAIR than they were for CHAIR. What this indicated was that the basic term, CHAIR, was the most cognitively efficient representation containing the maximum amount of information for the least amount of cognitive effort. Moreover, cognitive effort increases with having to recognize finer details about a particular category.

The exception to this pattern of attributes along the taxonomy occurred with biological taxonomies. In the case of biological taxonomies, American respondents listed just as many attributes for superordinate categories as basic level categories. Whereas Rosch (1978) interpreted these results as the result of the cultural environment — what we learn by being part of a particular society — Dougherty (1978), with her cross-cultural tests of the knowledge bases of Tzeltal Maya children and American children, interpreted Rosch's (1978) results as a lack of exposure to different plants and animals in the natural environment. In both cases, it is important to emphasize that the evidence points to structured information in the *local environment*, regardless of whether this environment is considered to be cultural or natural.

Another of Rosch's (1975) studies suggests that in addition to the concept that representations arise in the local environment (i.e. natural and cultural environments that subsume the respondents), there also seems to be a sort of *global environment* which generates representations. This global environment seems to produce representations that are intrinsic to the objects themselves and appear to be unrelated to the respondents' interaction with the local environment. In this test, Rosch had American respondents (Berkeley undergraduates) provided prototype scores for the species of bird they felt was most representative of the category BIRD. The results showed that the most prototypical birds were birds from the passerine order. Further tests correlating the order of the prototypicality scores with information that the respondents may have drawn from their environment revealed that the way the scores were ordered was probably not because there were more birds in the higher protypicality ranks flying around San Fransisco (i.e. natural environment), nor was it the result of there being more mention of the higher ranked birds in books and newspapers (i.e. cultural environment). Rather the prototypicality scores were highly correlated with the shape and behavior of *all* of the birds the respondents knew about (i.e. global environment). The species that were ranked highest were those species belonging to the largest orders and families.

The conclusion that can be drawn from these tests is that representations can be seen to form in the environment. That is, much of what the individual does involves seeking out the structure which already exists in the environment. This seeking involves embodied information processing as well, but if we accept Rosch's proposition that humans maximize the amount of information they can retain with the least amount of cognitive effort, then it would seem that the individual more likely than not takes full advantage of the preprocessing of the representations which the environment provides the individual. It should be noted that the local environment, specifically the cultural or social environment, subsumes the individual and this means that it can be inferred that individual cognition plays a role in the environment and the information it processes. The global environment, however, is different in that the global environment does not seem to be affected by any cognitive effort on the part of the individual.

The Objective of the Thesis in Relation to the Cognitive Anthropological Research Discussed

As can be ascertained from the above discussion, there are processes at work within the environment, local and global, that structure the information being internalized by the individual. This is similar to Alfred Gell's (1998:221-258) notion of "extended mind", but for one main difference, and that is that Gell (1998:222-223) primarily conceives of material objects as extensions of the mind, whereas I consider the environmental processes *involving the material items* to be manifestations of the mind. The implication that there are processes in the environment which structure information for the individual is that these processes — which can be conceptualized as systems — are no less cognitive than the neurological processes responsible for cognition within the individual. The concern of this thesis strictly surrounds the local environment, and specifically the social environment in the form of social systems or institutions and their role as cognitive sources.

Archaeology can contribute uniquely to the study of the social environment and how the processes therein can be seen to constitute supra-individual cognitive processes. The reason archaeology can offer a hand in this particular area is that the archaeological record is by and large a record of social processes, and archaeology is the only field that deals with time-depth that is necessary in many cases for inferring attunement to information in the social environment. Not only can archaeology help to illuminate the interaction between the individual and social environment, but it can help to illuminate archaeological questions, since by studying the social environment, one can arrive at a closer understanding of the individual who is internalizing the products of the social environment.

Above I discussed that an embodied modular hypothesis cannot account for how representations arise, or how they become long-standing, thereby forming cultural representations. The modularists propose that individual modules have their own information processing capability. This, however, was shown to be inconsistent with what we know about memory through Tulving's (1983) studies and therefore a modular theory could not by itself account for how cultural representations become long-standing.

A solution to this dilemma can be found in seeking for cognitive processes — information processing processes — outside of the individual, in the environment. The research of Gibson, Rosch, Berlin, Kay, and Dougherty strengthens research in this direction. They propose that many representations are already in a form that involves very little processing from the individual. What is primarily meant here by processing is memory storage. Thus, when I state that very little processing is necessary on the part of the individual, this basically means that the representation is already being stored in some process occurring in the social and/or natural environment subsuming the individual.

How can a social or natural process in the environment function as an external or supra-individual memory store and processor for the individual? One potential solution is suggested from archaeology, which by its nature is forced to privilege or favor environments and the effects of the interactions of ancient minds and the environment. My approach in this thesis, rooted in archaeology, accepts that the environment has the capacity to generate representations in a way that facilitates retention over time (i.e. the long-standing characteristic) and thus environment is involved in the generation of representations that qualify as social and/or cultural. The point that should be clear is that representations do not need to be stored in embodied modules. They can be stored in external stores, namely the social systems or institutions that comprise the social environment. The precise details of how a social institutional process in the environment can store representations for individual will be discussed later in the thesis. To provide this explanation however requires some knowledge of what cognition is, and I begin to explain this in the next chapters.

1.5 The Relevance of Studying Supra-Individual Cognition in Archaeology

The study of supra-individual cognition concerns archaeology in two ways, directly and indirectly.

Direct Relevance of Supra-individual Cognition for Archaeology

Cognition is directly relevant to archaeologists interested in the evolution of cognition and to those who are tracing the development of cognition from our australopithecine ancestors. Archaeologist Steven Mithen (2001:100) has proposed three directions cognitive archaeologists should pursue: mental modularity, sexual selection, and *extended mind.* He proposes that all three fall within the scope of cognitive archaeology, since archaeology has access to data directly relevant to these cognitive topics and it is therefore our responsibility as archaeologists to contribute to these topics with the archaeological evidence we have available to us.

Of most concern to me is the topic of extended mind. Extended mind or *externalism* is the notion that cognition is not confined to the brain but that it is coupled with the environment. Environment can include people, computers, a pencil and notepad, in short whatever it is that facilitates our cognitive capabilities outside of the neural substrate. The notion of externalism has its scientific roots in the psychological research of Gibson (1979), but the idea has been around before this in philosophy, as I discuss in Chapter 2.

The cognition I discuss in this thesis, namely supra-individual cognition, is related to the concept of extended mind and therefore falls within the domain of archaeological research. Archaeology can generate the data necessary to contribute to developing a general model of cognition which embraces externalism and the related concept of supra-individual cognition. Once the data are generated, it is important for the archaeologist to follow through with generating theory.

Indirect Relevance of Supra-individual Cognition for Archaeology

The basic premise is that by using archaeology to address issues, generate models, and solve problems in other fields, theoretical contributions can be made in other fields, which in turn facilitates archaeology in solving archaeological problems. Utilizing archaeology to solve problems in other fields constitutes a kind of investment for archaeology, from which archaeology can eventually reap the benefits.

Archaeologists should not merely generate data for cognitive scientists to interpret, nor should archaeologists merely adopt theories from cognitive fields to explain some aspect in the archaeological record. Instead, archaeologists should be active participants involved in the theory building process. To do this necessitates that the archaeologist involve himself or herself in research outside of what is generally regarded as archaeology in the conventional sense.

It is crucial for archaeologists to be concerned with answering questions outside of archaeology and not solely be concerned with explaining archaeological events. If we limit the scope of archaeology to only answering archaeological questions, the field of archaeology risks being a "sink" of knowledge, in which only tools from other fields are applied, rather than a source of knowledge of use to other disciplines.

Other fields will not be the sole beneficiaries of this knowledge, because in creating new theory, archaeology will be actively involved in generating theory for its own purposes as well. That is, by answering questions in other fields such as philosophy, sociology, and cognitive science, archaeology will in fact be producing theories that can in turn answer archaeological questions down the line. Only then can archaeology emerge as a more self-confident field, independently capable of producing theory for itself.

The study of supra-individual cognition, for example, not only generates ideas that cognitive scientists may work with, but it can also be useful to archaeologists in interpreting the archaeological record. Supra-individual cognition implies the existence of information that comes to the individual already processed by social institutions. Therefore, understanding how social institutions work can provide a very useful tool for archaeologists interested in knowing what people in the past may have been thinking about. In fact, developing a theory of supra-individual cognition would be invaluable for understanding what past people were thinking since much of the archaeological record is a record of social events. Understanding supra-individual cognition, therefore, can facilitate the archaeologist in hypothesizing emic perceptions.

Archaeologists should not only be concerned about what theory can do for archaeology, but rather what archaeology can do for theory (Elizabeth Graham, personal communication 2003). This thesis is an attempt at getting away from seeing ideas from the perspective of what they can do for archaeology and getting closer to seeing archaeology as a generator of new ideas.

Part I

The Nature and Location of Cognition

Chapter 2

The Quest for Cognition

Cognition is an elusive phenomenon, which philosophers have long sought to locate. This chapter will deal specifically with the question: "Where is cognition located?". This question is important because, in this thesis, I advance a concept of cognition which encompasses both subject (the individual) and the environment (the physical environment and/or other individuals that constitute society) and the reader needs to know that this idea is not as unconventional as it may seem when placed in the context of previous cognitive work in philosophy, psychology, engineering, and computer science.

This chapter acquaints the reader with concepts and debates that are familiar to cognitive scientists and philosophers. Only with a familiarization of the concepts and debates surrounding cognition can my notion of cognition be situated with respect to previous research in the cognitive sciences and in philosophy. And only with an understanding of the concepts and debates surrounding cognition can the reader see where my ideas on cognition originate, and see that my views represent a logical step in the direction in which the study of cognition is heading.

The material that I present in this chapter is treated chronologically from some of the earliest concepts of the mind to the latest ideas on the subject. What I would like to emphasize from the outset of this short historical account of cognition is the theme of the chapter, which is the development of views regarding the *location of* cognition. It should, however, become evident that the question of *where* cognition is located relies on resolving the question of *what* constitutes cognition. Only when the debate concerning what comprises cognition is settled can a home be found for cognition.

2.1 Universal Cognition

The idea of universal cognition was a rationalist construction, the main proponent of the paradigm being Georg Wilhelm Friedrich Hegel (1770-1831). What made the rationalist view of cognition unique was its emphasis that cognition was active. This contrasted significantly with the views of the sensationalists and empiricists, who advocated a form of cognition that only passively perceived and experienced. Cognition for the rationalists such as Immanuel Kant (1724-1804) was not a vat that simply filled with sensations and experiences. Instead, cognition was an entity that was actively engaged in processing experiences, the implication being that what we humans perceive to be reality is the product of cognition.

Like Kant, Hegel (1955:806-807) believed that all time and space is subject to cognition. We perceive reality by actively processing through our senses. Therefore, our interpretation of the knowledge we are actually presented with is our own construction. All knowledge, in other words, is "tainted", since it undergoes cognitive processing before it is finally interpreted. It is for this reason, therefore, that Kant believed that a reality "outside" our cognitive field and as a consequence, a *knowledge of* reality, are beyond our grasp.[1]

One of the main arguments for the impossibility of ever comprehending an untainted knowledge — what Kant refers to as the "thing-in-itself" — was the fact that Kant claimed "to know" that the thing-in-itself was unreachable (Waxman 1991:220-221). But how would Kant "know" if something was unreachable if it was beyond anyone's ability to comprehend to begin with? Kant's reasoning was claimed to be a tautology, and as a result Kant received some criticism from philosophers such as Johann Fichte (Hegel 1955:80; Baillie 1955:38), who stated that what one's mind cannot know does not exist. By making this simple statement, Fichte was able to turn Kant's reasoning on itself, thereby reasoning against the possibility of the existence of untainted knowledge.

In contrast to Kant, Hegel (1955:80-81) believed that the thing-in-itself could be comprehended. Hegel reasoned that if the thing-in-itself existed then it was possible to show that it existed objectively, through reason, not through subjectively knowing of the thing-in-itself's existence. The goal then for Hegel was to create the first comprehensive scientific theory of cognition that could account for the changes that are effected in the mind, which subsequently "tamper with" the thing-in-itself. By understanding the process involved in cognition, the distortions that are imposed on the thing-in-itself could be subtracted, thus bringing the individual closer to the thing-in-itself.

[1] If this sounds familiar to the archaeologist, it probably is. The material culture movement (Hodder 1982; Shanks and Tilley 1987; Tilley 1989), which has its roots in semiotics, is all about "signs" and how they are taken to signify ideas in the mind. We construct these signs, whether in the form of language or material objects, which, in turn, construct the way we perceive our environment, indeed our world. Like Kant, many semioticians also believe that we can never know the world outside of the signs we use to construct the world.

Hegel later adopted the term "the absolute", which he often equated with God (Baillie 1955:21), in place of the thing-in-itself.

Hegel believed it critical to understand how the absolute could come to be realized, but in order to do so a path had to be cut through the representations of the absolute. The approach, which Hegel would take, was to be known as the "dialectic process".

2.1.1 Hegel's Dialectic Process

Hegel's notion of cognition operates through the dialectic process (Hegel 1955:122-123), which is a triadic system of reasoning that entails three sub-processes: speculative thinking, ordinary skepticism, and particular skepticism (Rockmore 1997:17-19). Speculative thinking contrasts with the latter two kinds of reasoning in a significant way. Speculative thinking conjures up a representation, which is often referred to as a *thesis*. In reaction to the thesis, skepticism arises, which counters speculative thinking with either complete or incomplete denial of the thesis proposed.

In the case in which the thesis is denied completely, it is called ordinary skepticism. According to Hegel, it is frequently the case that vanity motivates one person's attempt to refute another person's thesis (Rockmore 1997:19).

In the case where only particular aspects of the thesis are denied, it is called particular skepticism. In this case, only certain features of the original thesis are accepted whereas other features may be refuted.

In either the ordinary or particular cases, the thesis is countered by a skeptical *antithesis*. Within both the thesis and the antithesis, there exist certain untrue aspects about each of them. This is proven by a third representation called the *synthesis*, which eliminates elements of falsity from both the thesis and the antithesis. In other words, the synthesis is a hybrid of thesis and antithesis which, because it has subtracted the erroneous elements from the thesis and antithesis, is a closer rendering of truth than the thesis and antithesis ever were.

The dialectic process, however, does not abate as soon as a synthesis arises from the thesis and the antithesis. Instead, the synthesis continues, but this time, playing the role of thesis, which again is countered by another antithesis, creating this time a new synthesis. Each subsequent iteration leads cognition closer to the absolute. The absolute, therefore, is the final result of this dialectic reiterative process.[2]

2.1.2 Discussion of the Resemblance of Hegel's Dialectic Process to the Bisection Method

The resemblance of the dialectic process to a common iterative procedure called the *bisection method*, which is used in mathematics for finding the roots of *continuous* functions (Gregory and Redmond 1994:37-39), is noteworthy. [3] Based on the Intermediate Value Theorem, the bisection method begins

[2]This method of finding truth resembles a famous thought experiment, which was proposed by Democritus and by other atomists to elicit the atom. In this thought experiment, atomists required one to imagine a material object being halved, and then one of the halves being halved *ad infinitum*. The result of this reiterative dissecting, claimed the atomists, would be an indivisible particle called the *atom*.

[3]A *function* is a *mapping* from one set of numbers to another set of numbers, or from a domain of values (e.g. real or natural numbers) to a range of corresponding values (Haaser and Sullivan 1991:5). For example, $f : R \rightarrow [0,1]$ is the function, f, which maps the set of all real numbers (i.e. between negative infinity to positive infinity) to the set of real numbers between 0 and 1. Commonly, functions map from the set of all real numbers to the set of all real numbers. For example, the function $f(x) = 2x$ is such a function, since it can take any real number for x on the right-hand side of the equation and it outputs an associated real number for $f(x)$. Geometrically, this is a line in two dimensions with

by considering a range of values of x, containing the root. Then one selects a point in the range (commonly the midpoint in the range) and substitutes the value of the point in for $f(x)$. This will result in either a positive or negative value for $f(x)$. If $f(x)$ is positive then one halves the lower division of the range (so that the original range is now quartered) by choosing the midpoint in the lower division of the original range, and substitutes it in for $f(x)$. If $f(x)$ is negative then one halves the upper division of the range by choosing the midpoint of the upper division of the original range. This procedure is reiterated, each time dividing the range further, until a value for x, when substituted into $f(x)$, gives $f(x) = 0$. At this point the iterations can halt, since the root is revealed.

Here, Hegel's thesis and antithesis can be conceived of as the *least upper bound* (lowest number in the range) and the *greatest lower bound* (greatest number in the range). It does not matter which is the thesis and which is the antithesis, since the thesis and antithesis in the quest for the absolute are completely arbitrary representations. In other words, they are just two kinds of knowledge, which may or may not be the absolute. Mathematically, the absolute can be conceived of as the root that we are searching for, and the synthesis as the value between the extremes that one has chosen to substitute into the function, $f(x)$. The quest for the absolute, then, is the systematic selection of numbers that produces subsequent renditions that are continuously getting closer to the absolute. The absolute is encountered when the process can go no further or until the thesis or antithesis become identical or nearly identical to one another for all practical purposes.[4]

indefinite length. A root is simply the value of x where the function, $f(x)$, intersects the x-axis (i.e. $f(x) = 0$).

[4]I must admit that this technique is not infallible. For instance when the root happens to be an irrational number, the root may never be completely comprehended numerically.

The interesting point in all of this is that the Intermediate Value Theorem can be adapted into a computational algorithm that can be used to solve equations numerically, and it works provided that the range containing the root is known. It cuts straight through the different values in the range to the actual root. A root can be any value in the range and yet this simple algorithm, for all intents and purposes, manages to home in on the root.

2.1.3 The Scale Independence of Hegel's Cognition

As the resemblance of Hegel's dialectic process to the bisection method suggests, Hegel's theory of cognition (i.e. the dialectic process) can be regarded as a computational view of cognition, which has been a common way of conceptualizing cognition in the cognitive sciences since the 1950s (e.g. Turing 1950, Reisberg 1997). By envisioning cognition in this way, it can be argued that Hegel saw cognition as being transposable at different scales. This is because Hegel saw cognition as a process which could be abstracted from its context, and therefore a process which could occur independently in the brain of the individual, in society, or even in the world as a whole.

For example, Hegel's dialectic process entails that with regard to the first scale (i.e. the brain), a single individual could come up with an arbitrary idea by himself or herself (i.e. a thesis), but then after deliberation find that an opposite view is more adequate (i.e. an antithesis). He or she could, then, eventually develop the idea even further (i.e. into a synthesis).

By the same token, the dialectic process could occur within society amongst

An *irrational number* is a number that has an infinite number of decimal places, like the natural number, e, and so the iterations can potentially go on forever, never arriving at a definitive number. Nonetheless, when rounded to a certain number of decimal places the root is realized for all practical purposes.

several individuals. Within the confines of a society, one individual could come up with an idea, while another individual could skeptically refute it, a synthesis of the ideas could follow, at which point the synthesis could become the fledgling thesis, and so on.

According to Hegel, no society is completely closed and so entire societies, which communicate with each other, can be involved in the dialectic process as well as individuals and groups of individuals. In this manner, the dialectic process operates on many scales, and if one takes the scaling of cognition to its logical conclusion, as Hegel did, then one could eventually conceive of a kind of cognition that includes all of humankind and perhaps even the universe.

An important point to remember about the dialectic process is that at each scale, cognition is cumulative through time and history (Hegel 1956). To see how cognition accumulates in this scale independent model, and to see how the cognition occurring within the brain of an individual and the cognition occurring within society will eventually become one, it is important to see that not only does the dialectic process occur at different scales from the human brain to the the level of communities and states, but that the theses that arise in each of the different scales are fundamentally the same. The theses are the same on each scale because they are all creations of the lowest scale — the brain.

An example of how a thesis exists in the brain and in society is the thesis of "communism". It is a thesis that goes through independent dialectic processes in the human brain, among individuals, and among states. On all scales, the thesis of "communism" goes through dialectic processes with its antithesis "capitalism". Whereas the dialectic process can manifest itself on an inter-individual scale as an argument, it has manifested itself on the state scale in the form of war (e.g. Cold War, Korean War, Vietnam War, etc.).

Though it could be said that the higher scales of society (e.g. the state) are dependent on the lower scales (e.g. the brain) for their ideas, it can be inferred from Hegel that the dialectic processes on each scale are fundamentally different from each other and can therefore be regarded as independent processes. This scale independence prevents what happens in our brains from happening automatically on the state level.

If the theses are the same on each scale and if the dialectic process is occurring at each scale, then each scale will arrive at the absolute independently. Eventually it will be realized by the individual brain that the absolute has been reached at which point "individual" cognition and "societal" cognition catch up with each other, becoming one.

The idea that cognition operates independently on different scales is not incompatible with the view I take in this thesis, which is that cognition is substrate independent and therefore scale independent. However, it is important to emphasize that although cognition is scale independent in the abstract sense, the scales of cognition are hierarchical and therefore influence each other. The reason I hold on to the abstracted notion of cognition is that it facilitates the conceptualization of a more general model of cognition which I take the first steps in expounding in Chapter 8.

2.1.4 History's Role in Hegel's Cognition

If individuals are deliberating about their own ideas and pedagogically learning past theses and how these theses were debunked or modified in this hypothetical society, then the individual — though he or she may have reconceived an exact duplicate of a thesis that failed — will likely decide against proposing the idea since the weaknesses of the thesis have been demonstrated historically. As a result, an individual born on this earth will rapidly learn what theses have been proposed, and therefore will more likely than not propose only new ideas built upon the old ideas. In this way, the knowledge of an individual at any point in time is, in theory, the knowledge that has accumulated in society. Since much of what is stored in the individual's brain is social, then we as individuals are in effect serving the whole, which in this case, is society. What this means is that over the long term history is society's memory, which is constantly propelling society toward the absolute; and so are the individuals that make up society approaching closer to the absolute.

A society, therefore, has a memory that transcends any individual biological memory. Mistakes that are made in the past are recorded into social memory and are subsequently — at least in theory — never reiterated in exactly the same way. Cognition therefore rarely, if ever, circles and finds itself in exactly the same place. Cognition is cumulative and teleological, and this is evinced from history.

In this sense, history has a very important role in Hegel's idea of universal cognition. In fact, it was pointed out by Engels that history is the proof that Hegel's view of cognition is valid (Marx and Engels 1951:337-338). Hegel envisions history as having a purpose, and that purpose is every human's search for freedom (Hegel 1956:12-13). This is not some abstract freedom, where everyone follows one's desires, but rather a freedom of conscience, which Hegel adopts from Kant. According to Kant, action is the result of desires and reason, but since desires, regardless of whether they are innate or social, were not chosen by us, people cannot be truly considered free (Singer 2001:39). In other words, we are prisoners to our own desires, since we have no control over their occurrence and since they often move us to act.

Therefore, following desires is not the route to freedom and this consequently leaves us to our own reason (Singer 2001:39-40).

Action based solely on reason is possible according to Kant if all desires are taken out of the equation (Singer 2001:41). What we are left with is Kant's "categorical imperative", which is in and of itself universal morality. What, then, does acting according to the categorical imperative feel like? According to Kant, it should feel like doing one's duty (Singer 2001:40-42). That is not to say that one should feel obligated to do one's duty according to some social ethos or innate desire, but the feeling should arise from one's own individual conscience. Regardless of the actions that ensue as the result of rational thought, all actions will have at their heart the one common denominator, which is the driving force, and that is duty for duty's sake.

History is the process by which the realization of duty as freedom unfolds, the goal of history being this realization. Hegel's view is not quite an evolutionary view of history, since evolution is not usually regarded as being teleological, yet it is similar to evolution in that Hegel did consider history a developmental process. Specifically, Hegel's history was the developmental progression toward a consciousness of freedom (Singer 2001:15).

The development of a consciousness of freedom is integral for the search for the absolute, which was discussed above, because being aware of one's freedom clears any superfluous thoughts, such as desires, that might interfere with the rational quest for absolute knowledge. Similarly, achieving absolute knowledge through a historically manifested dialectic process culminates in consciousness of freedom. Thus, the search for the absolute and consciousness of freedom are indelibly linked since they achieve the same result from disparate perspectives.

Hegel's history consists of four main phases, which occurred in four different parts of the world, namely: the Oriental world, the Greek world, the Roman world, and the Germanic world (Hegel 1956). Hegel's history stops with the Germanic world due to the fact that Hegel believed that the goal of history was finally attained in the 19th century German state, specifically with the publication of *Phenomenology of Mind*. This is because it was within the pages of *Phenomenology of Mind* that people were supposed to realize that they were truly free. Hegel wanted to make his thoughts the turning point, when individual freedom of conscience was finally realized.

2.1.5 Discussion of the Hegelian View of Cognition

It should be evident from this short summary of Hegel that what Hegel was trying to create was a scientific theory of cognition, in which cognition had an active role. Cognition was not only a medium through which ideas traveled; it had a role to play in creating and questioning ideas. This was accomplished through reason and, thus, to a certain extent, cognition for Hegel was reason. Hegel was also a firm believer that there existed one moral edict or rationality which was universal — the categorical imperative (duty for duty's sake) — and that in the absence of coercion, all paths eventually converged on it.

It can be said that the *Phenomenology of Mind* is a "how to" book rather than a book describing how cognition actually operates. Hegel seems less concerned with how the mind actually functions under normal circumstances than he was concerned with looking for a way to arrive at the absolute. One valuable point can be extracted from Hegel's conception of cognition. Because cognition was reason (for Hegel), and because reason was universal (for Hegel and Kant), it followed that cognition was ultimately universal. Consequently, this can be interpreted in several different ways, two of which are: that individual minds are linked because they share this universal reason or, as Hegel proposed, that individual minds are aspects of universal cognition (Singer 2001:89). (On this point Hegel's interpretation is surprisingly consistent with my interpretation of cognition, which I explain in Chapter 8, though I do not propose a universal cognition but rather a kind of "societal" cognition, which I refer to as supra-individual cognition.)

The presumption, however, that cognition is reason and that reason is universal is problematic. Anthropology has taught us that not everyone abides by the same categorical imperative, which is duty for duty's sake. Not all people are rational in the same way and therefore not all people will arrive at the same conclusion. The assumption that there is one final form, or truth, at the end of the progression of society, is a presumption and nothing more.[5] Still, what Kant and Hegel have taught us shows from a theoretical perspective, at least, that cognition can be seen to exist outside of the individual, at the same time subsuming the individual. It may not be the universal omnipresent cognition that Hegel thought was possible, but it does suggest that clusters of people thinking along the same lines could form an extended cognition.

For Hegel, cognition pervaded societies and even larger organizations of individuals. He was a holist in this regard, since he believed that individuals played only parts in society and that these parts, in themselves, amounted to little given that individual cognition would, in time and driven by history, become synchronized with what I would refer to as "societal" cognition.

[5]The bisection method, used as an analogy to the dialectic process, demonstrates this point adequately. If the continuous function that is being analyzed with the bisection method has more than one root, then different initial ranges may contain different roots. In terms of the dialectic process, multiple roots translates into multiple "absolutes".

2.2 Cognition Is in the Brain

The notion that cognition was scale independent remained an important concept for philosophers for many years, but it steadily declined in popularity with the advent of scientific psychology (Hergenhahn 1992:207). The reason that people became less concerned with scale independent cognition was a change in methodology that turned interests toward the individual (Hergenhahn 1992:207), but there was no significant refutation of the scale independent model. The demand to place the study of cognition on a scientific footing arose, but to use scientific techniques, it was necessary to have something to observe physically, such as material or behavior — a *substrate* was required. Because cognition was difficult to observe without a substrate, the tendency to study the effects of cognition on the physiology of the individual and the behavior of the individual in isolation began to grow.

During the 17th and 18th centuries, observations of human behavior would lead to a stream of developments that would later characterize the foundations of modern experimental psychology (Hergenhahn 1992:207). The very first of these observations were for the most part accidental. For example, in the 17th and 18th centuries, clocks were set according to the precise locations of specific stars in the night sky. This was often accomplished by an observer setting the clock precisely as a specific star crossed the hairline of his or her telescope. However, consistent discrepancies between the time it would take for two individuals to observe a star-crossing and the time it would take to set their clocks were noticed (Hergenhahn 1992:207).

This suggested that reaction times in individual perception varied and that these differences could be formally expressed mathematically (e.g., John's clock is always a tenth of a second slower that Bill's clock). This meant that not all individuals process information as speedily as others, and that cognition or at least aspects of cognition, such as perception, differed to some degree among individuals.[6] The reaction, then, for burgeoning scientists of the mind was to eradicate the notion that cognition was the socially or universally enveloping phenomenon it was thought to be. This meant that the study of the mind could proceed from the individual, not from society or some larger social unit of investigation in the way that Hegel believed. It also meant that as long as experiments managed to isolate certain aspects of cognition, such as perception, from interferences, it was possible to study these aspects of the individual mind scientifically.

Developments in physiology and the subsequent emergence of experimental psychology changed how we conceive of the mind. The idea that the secrets of the mind were hidden within the individual was not new, for it was a view that was advocated by Descartes (Hergenhahn 1992:209). Descartes saw the nervous system as consisting of a complex series of tubules, which were routed from a special gland — where ideas ("animal spirits") were conceived — to a fibrous brain. Ideas flowed through these tubules to the brain, enlarging the gaps between the brain fibers. Stronger ideas left larger gaps between the brain fibers and hence left deeper impressions on the brain. In this way, ideas regarded as spirits could directly impact material (i.e., the brain) (Descartes 1985:107 in Seager 1999:6-7).[7] It was not until the 19th cen-

[6]For most cases it was nearly the same but in terms of research emphasis, minute discrepancies took priority over commonalities.

[7]The notion of there being two different substances in the world, spirits and material, is known as *Cartesian dualism*. In later years, the study of cognition settled on a form of *monism*, called *materialism*. However, for some philosophers of consciousness (e.g. Chalmers 1996), dualism still remains an important doctrine. Another dominant feature in Descartes' work, which also happens to be a consequence of dualism, is the *mind-body problem*. The mind-body problem is one that addresses how physiological events work to produce mental events, and how mental events, in turn, work to produce physiological

tury, however, that progress into studying nerves (Descartes' tubules) led to developments in distinguishing different kinds of nerves. Charles Bell (1774-1842) and François Magendie (1783-1855), for example, were the first to be able to distinguish motor nerves from sensory nerves (Hergenhahn 1992:209).

Around the same time that physiologists were shedding light on the human nervous system, advances in psychology were being made. It was at this time, for instance, that *faculty psychology* emerged. Thomas Reid (1710-1796) was the first to use the term "faculty" in a meaningful way (Hergenhahn 1992:170). Before him, others used the term loosely as a way to describe any kind of mental ability; but it was Reid who was to consider seriously what kinds of faculties humans have. Reid concluded that there were 43 mental faculties and that these faculties were innate. Breathing, swallowing, resting, and feeling were just three of the 43 mental faculties that Reid recorded. Whereas innate mental abilities were regarded as faculties, acquired mental abilities were referred to as "habits". Reid believed that faculties never operated alone, only as parts of a single mind.

It was the anatomist Franz Joseph Gall (1758-1828) and his student Johann Gasper Spurzheim (1776-1832), however, who were integral in equating the mind with the brain and with it all of its faculties (Hergenhahn 1992:220-221). Three claims, made by Gall and Spurzheim, were to accomplish the task of shifting the the study of the mind to the brain. The first claim was that the strength of mental faculties varied from individual to individual; no two individuals have the same faculties to the same degree. The second claim was that these faculties are all housed in specific areas of the brain of the individual. And the third claim was that these faculties can be identified and studied by feeling or looking at the bumps on a person's head.

effects.

This third claim was supported by the belief that well developed faculties cause protrusions on certain regions of the skull. The study of surface features on the head became known as *phrenology* and it became popular as a means of divining characteristics about one's mental capacities (Hergenhahn 1992:171-174).

Ironically, it was subsequent faculty research, conducted by phrenologists, which was to show that many of the assumptions that were made by phrenologists were false. Nevertheless, what Gall and Spurzheim did achieve was to situate the mind firmly within the skull of the individual and to present the first modular view of the brain, which was to remain popular in neuropsychology for many years to come (Hergenhahn 1992:174).

Advances into how the brain functioned were made by psychologists and physiologists in subsequent years, but one of the most important breakthroughs was the discovery of the neuron at the end of the 19th century by Santiago Ramon y Cajal (Churchland and Sejnowski 1996:40-44). Up to this time, anatomists had to tease apart brain tissue carefully in order to observe individual cells. Often this resulted in inaccurate depictions of individual cells. To isolate individual cells, anatomists began to stain their samples, in the hope that the staining would cause the individual brain cells to stand out. Unfortunately, these rudimentary staining methods discolored entire arrays of cells and did little to illuminate the structure of the individual cell. Ramon y Cajal (1894), using a *silver impregnating* staining method discovered by Camillo Golgi, became the first to stain only a few random cells, or neurons, thereby becoming the first to observe a single neuron with all of its distinctive features (Levitan and Kaczmarek 2002:8).

Since this discovery, great advances toward elucidating the operative mechanisms of neurons and how they interact with other neurons to produce cognition have been made (e.g. McCulloch and Pitts 1943). However, to understand how neurons function as the fundamental constituents of cognition it is necessary to discuss, in detail, the structure of the neuron and the networks that neurons form.

2.2.1 The Neuron

The neuron comprises two main parts (the following is summarized from Wu 2001:1-8): the *cell body* or *soma* and the *axon*. The cell body contains the *nucleus* and has several root-like protrusions called *dendrites* which extend to other neurons. The axon is a long fiber-like protrusion, which also extends to other neurons. Typically the furthest ends of the dendrites and axon can fan out to as many as 10,000 other neurons. The furthest ends of the dendrites and axon do not actually make contact with other neurons; instead there are gaps called synapses, normally 20 nanometers in breadth, which separate the ends of the dendrites and axon from the other neurons. The purpose of the dendrites and axon is to link other neurons so that they may interact. They interact by sending electrical impulses through the dendrites and axon until they reach the *synapse*, a bulb-like structure at the end of the dendrite or axon which contains several *presynaptic* sites. If the magnitude of the electric impulse is strong enough, a presynaptic site releases chemical neurotransmitters which cross the synaptic gap, contacting the *postsynaptic* sites on the cell bodies of other neurons. In this way, interaction between neurons is achieved by electrical as well as chemical means, and the main difference between these two means is in the speed at which they propagate.

The electrical impulses, which are propagated along dendrites and axons of neurons, are generated as the result of incoming chemical neurotransmitters exciting the synapses of cells. The excitatory synapses then emit an electrical impulse into a negatively charged axon (the neuron's equilibrium potential is about $-70mV$ in comparison with a positively charged liquid exterior). The rising positive charges in the cell cause a loss in the impermeability of the membrane. This allows positive ions, such as Na^+, to flood into the cell, causing the interior of the axon to go positive ($+60mV$). The now positive interior causes permeability from the inside out. This action initiates an impulse that propagates down the axon, allowing positive ions, this time K^+, to leak out of the cell until the $-70mV$ equilibrium within the cell is again achieved. The impulse then propagates down the axon to the next neuron, and in this way signals are propagated throughout the cell body (Wu 2001:2-7).

In the brief discussion of individual neurons above, it was mentioned that the electrical impulse, produced as a result of the ionic discrepancies between the interior and the exterior of the cell, is the means through which neurons interact with each other. What aspect of the signal *pulse train* actually effects responses in neurons is still a matter of some debate (Milton 1996:21). For instance, whereas some believe that it is frequency of the pulse train, others claim it is the intensity of the pulse train that allows neurons to interact with one another. However, this is not an issue for many cognitive scientists, because many cognitive tasks can be explained without a precise understanding of the actual signals being transmitted among neurons. These tasks to which I refer are the information-processing aspects of cognition, such as learning, recalling, and recognizing. These tasks are dependent not on the bottom-end properties of neural interaction (i.e. the kind of signal being transmitted between neurons), but rather on the top-end properties of neural interaction (i.e. the interaction of neurons in the neural network as a whole). This realization came about as the result of physiological and mathematical inter-disciplinary research being conducted in the middle of the 20th century. Three discoveries stand out at this point marking the beginning of this "cognitive revolution".

The first was the discovery that neurons have specific roles within the neural network they comprise. McCulloch and Pitts (1943) discovered that built-in thresholds within neurons, dependent on the electro-chemical environment, have to be overcome in order for neurons to fire impulses; if this threshold is not overcome, neurons remain inactive. This one property of the neuron has far-reaching implications, for it is this on/off mechanism that allows information to be processed. This mere property of the neuron in itself is insignificant, until we consider entire networks of neurons interacting in this on-off fashion. The human central nervous system has a vast number of neurons and mutual connections between these neurons. For example, a given cell in the human cortex receives input from as many as 10^4 synapses at one time. This high connectivity and complex parallel structure have a great impact on the number of various complex tasks a brain can accomplish.

The second discovery was that the brain is malleable to a degree. This feature is referred to as *plasticity* and it is another feature which adds to the overall complexity of the human brain. The synaptic strengths between neurons vary according to the intensity of usage of the synapses, since more active synapses are usually stronger than less active synapses (Hebb 1949). This quite elementary observation set the stage for the very first *connectionist* or *parallel distributed network* view of cognition (McClelland and Rumelhart 1986).

Hebb's (1949) work suggested that learning and other cognitive tasks have a neuro-physiological basis. The premise is that if ideas can be represented by neurons, then learning that two ideas are related in some manner is equivalent to the neuro-physiological act of strengthening the bonds between the neurons representing the ideas. What this suggested was that the properties of neural networks were the main factor in producing cognition, not the individual neurons themselves.

A single neuron has one fundamental property: an internal threshold (McCulloch and Pitts 1943).[8] It was inconceivable, therefore, that a single neuron had the capacity for complex cognitive tasks. It was more likely that neurons arranged in multiplex networks would be able to do complex tasks such as learning, storing, and recalling information. In other words, it began to appear that emergent cognition was a holistic phenomenon dependent on the network rather than the node. A short description of neural networks is therefore necessary in order to gain a general understanding of the underlying mechanics of cognition.

2.2.2 Network Architecture

Neural networks can be broken down into two types of architectures, feed-forward networks and feedback or recurrent networks. Typically, feed-forward networks are used in constructing artificial neural networks for engineering applications, whereas recurrent networks occur naturally within the nervous system. That is, biological neural networks are generally regarded to operate like feedback networks, since they have the capability to learn by themselves and this capability most accurately represents the autonomous way in which neural networks in the brain operate (Haykin 1999:392). Since the concern in this section is with cognition and the cognitive capabilities of the neural networks of the nervous system, I will focus on recurrent networks. Much of the

[8]Neurons also have internal decay rates (every neuron decays at a certain rate through time but this can be ignored for the time being).

following discussion on network architecture is taken from Thiran (1997:6-8) and Rao and Rao (1995:1-19).

Feedback or Recurrent neural architectures are networks of neurons that consist of only one layer of neurons, which function both as input and output neurons. Information that is input into the network is propagated among the neurons in a circular manner since the output and input neurons are one in the same and, therefore, form a system. Within this system, the input of a neuron is the output of a preceding neuron multiplied by the interconnection strength between the neurons. This process is reiterated until the system stabilizes at a particular level of activity. This process of reiteration is a dynamic process; therefore the neural networks that are engaged in this reiterative behavior are called *dynamical* neural networks. Because these neural systems frequently form nonlinear systems, different finite numbers of final output states (i.e. equilibria) can arise. Feedback neural networks are often used for learning, recalling, and recognizing information patterns.

A common mapping algorithm that can be used for a feedback network is:

$$y_i[n+1] = f\left(\sum_{j=1}^{n} w_{ij} y_j[n] + \gamma_i\right), \tag{2.1}$$

where $f(\cdot)$ is a *normalized signal function*, which is explained in the neural dynamics section, γ_i is the threshold for the normalized signal function, $y_j[n]$, $n \in \aleph$, is an input vector, $y_i[n+1]$ is an output vector, which is then fed back into the recurrent network as an input, and w_{ij} are *connection weights* that are associated with a signal being transmitted from the jth neuron to the ith neuron.

Feedback networks are unique because of their dynamical properties which

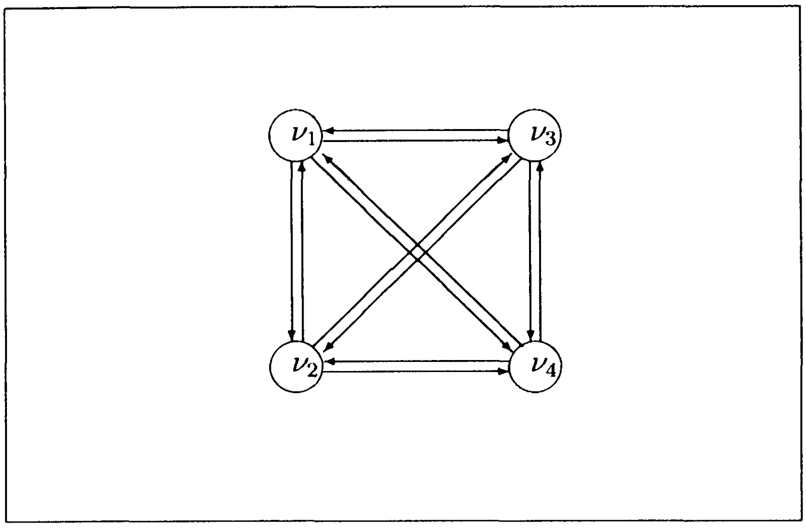

Figure 2: This network is called a Hopfield network and is an example of feedback network architecture. Here, ν_1, ν_2, ν_3, and ν_4 all act as input and output neurons. Notice that the nodal interaction occurs in both directions until stability of the dynamical system is obtained. The connections between the neurons can be weighted with values other than the binary values of 0 (which implies that there is no connection between two neurons) and 1 (which implies that there is a connection between two neurons).

enable feedback networks to learn by themselves (Rao and Rao 1995:5). The capability of recurrent networks to learn by themselves is called **self-organization** or **unsupervised learning**. A feedback network needs only to be provided with input information (i.e. a stimulus) and it will learn to respond in a specific way. The reason that a feedback network can achieve such autonomy and learn by itself is that the network *itself* abides certain rules; that is, the nodes of the network interact in a certain fashion which can be construed as rules. Provided that these rules are followed, the network can learn on its own without the need of a supervisor. A feedback network will learn, thereby forming memory, and will recall information that was stored into memory (i.e. respond according to the rules followed by the network). In networks that form nonlinear systems, this type of memory is called Content-Addressable-Memory (CAM) (Wu 2001:61-62).

2.2.3 Summarizing Neurons and Neural Networks

It was discovered through the study of the brain that the constituents of the brain — neurons — have an extremely simple function, which is that a neuron has an internal threshold that must be overcome in order for a neuron to fire. What this means is that cognition is not dependent on some complex innate property within the neuron, but rather it is dependent on some holistic property that several simple operating components linked together achieve by virtue of their holism.

The brain is a unique organ in that it can accomplish a multitude of complex tasks. However, the brain is not an enigma with regard to its information-processing capacities to store and retrieve patterns. These cognitive capacities, as neuro-physiologists have shown, are best explained as holistic properties of networks in which the constituents of the networks, neurons or their equivalents, play only a minor role.

Typically, the neural networks of the nervous system are recurrent networks, which have the ability to self-organize or self-learn. These feedback networks already have much of the information they need to learn on their own built into the network and only need stimulus information to utilize the stored information. The unique capability of recurrent networks to store and retrieve information on their own cannot be emphasized enough for neural networks and, as we shall see in subsequent chapters, for exchange networks that are preserved in the archaeological record.

2.3 Cognition as Computation

I will now move on to another discovery that occurred at the same time that physiologists and anatomists were uncovering the secrets of the neuron and the neural network. Unlike the previous two cognitive discoveries, — McCulloch and Pitts' (1943) discovery of the simple role that the neuron plays and Hebb's (1949) discovery that neurons can learn and recall information as networks — which maintained some connection with the neuro-physiology of the brain, this cognitive discovery would come from a purely mathematical source.

2.3.1 Precursors to the Computational View of Cognition: Behaviorism and Cognitive Psychology

Between about 1930 and 1950, behaviorism was the dominant theory in psychology (Hergenhahn 1992:542). Behaviorism emerged from the functional school of thought and it consisted of the assertion that much if not all of human cognition can be deduced through the observation of human beings.

This view contrasted sharply with the mentalist school, which believed that the object of study should be the human mind itself. The main way for the mentalists to observe the mind directly was through introspection. The problem with introspection, claimed the behaviorists, was that it conflated observer and subject, and it therefore was not as scientific as observing the subject from an objective position. The problem with observing the subject's behavior, claimed the mentalists, was that the observer loses track of the objective of the study, which should be the human mind. In other words, the behaviorists were not studying the mind; they were studying the effects of the mind, which were materialized in the form of human behavior.

Nonetheless behaviorism emerged as a powerful contending school of thought during the early 20th century (Hergenhahn 1992:335-336). Behavioral psychology, called objective psychology in its infancy, progressed mainly through the work of Russian psychologists: Ivan M. Sechenov (1829-1905), Ivan Petrovitch Pavlov (1849-1936), and Vladimir M. Bechterev (1857-1927). It also developed independently on the other side of the Atlantic with John Broadus Watson (1878-1958) and William McDougall (1871-1938) (Hergenhahn 1992:336-369).

Watson described the objective of behaviorism as deducing human responses from stimuli as well as inferring stimuli from observing human responses (Hergenhahn 1992:346-359). In other words, behaviorists conducted repetitive studies on human subjects to discover patterns in human responses. If behavioral patterns emerged from these studies, then one could use this knowledge in one's observations of human behavior to infer the stimuli that elicited the responses in the first place. In this way, great insight could be gained into cognition — or how someone will *react* — from studying the relationship between stimuli and responses in a controlled environment.

An example, which illustrates this kind of approach, is Pavlov's well-known study of the conditioned and unconditioned stimulus and response (Hergenhahn 1992:338-346). In his study, Pavlov discovered that organisms innately respond to certain environmental triggers. Food, for example, that is presented to organisms triggers certain biological responses such as the secretion of gastric juices and saliva. Triggers, such as presenting food to a dog, are called *unconditional stimuli*. Responses to these stimuli are called *unconditioned responses* (in the case of a dog presented with food, the unconditioned response would be the secretion of saliva). What Pavlov discovered was that if the unconditioned stimulus is preceded by a *conditioned stimulus*, such as the ringing of a bell, then the dog anticipating food will secrete saliva conditionally. That is, though the food is not yet in the presence of the dog, the dog will nonetheless elicit a *conditioned response* (i.e., the secretion of saliva in response to the bell). To elicit a conditioned response, the conditioned stimulus must be temporally associated with the unconditioned stimulus several times over before the dog will elicit a conditioned response. Presenting the dog with a conditioned stimulus and, shortly after, an unconditioned stimulus repetitively is called *conditioning*. What Pavlov found was that during conditioning, the dog was actually learning through associating the conditioned stimulus with the unconditioned stimulus. He called the nervous system activity associated with this learning process *excitation*, since a pattern was being engrained in the dog's behavior. However, Pavlov also found that this behavioral pattern of eliciting a conditioned response can be erased if the unconditioned stimulus no longer follows the conditioned stimulus. The nervous system activity associated with this learning process, or unlearning process, is called *inhibition* (Hergenhahn 1992:342).

Behaviorist studies, though they offered a scientific basis for studying the physical manifestations of the brain, bypassed what actually occurs in the brain. Behaviorism was interested in studying behavioral stimuli and responses presented to and elicited from brain; the brain as a separate focus played little or no role.

Not content with the miniscule attention paid to elucidating the mechanisms within the brain, the Gestaltists (e.g. Koffka 1963) and the methodological behaviorists (e.g. Tolman 1948) countered the behaviorist movement, and as a result initiated the emergence of cognitive psychology. Consequently, the mind-body problem resurfaced with the reemphasis on what actually occurs within the mind (Hergenhahn 1992:545).

The mind-body problem is an indelible feature that has appeared throughout the history of psychology (Hergenhahn 1992:14-15). The reason for the problem was the admission of mental events to a physical world. The behaviorists claimed that it was only behavior that was of consequence to the psychologist, since it is only behavioral manifestations of the brain that can be observed. They proposed that there was no need to study something that may or may not be occurring within the brain, and this therefore implied that there was no reason for hypothesizing the existence of so-called mental events. Behaviorists, hence, managed to resolve the mind-body problem quite concisely by denying the existence of mental events and embracing a materialist view of the brain via behavior. Behaviorists were monists in this regard, since they only accepted the existence of one substance, material, in the form of observable behavior.

For cognitive psychologists, the mind-body problem could not be resolved as easily as it was resolved for behaviorists. The mind-body problem was also more specific than it was for other psychological schools of thought in the past. It was not that cognitive psychologists were interested in the connection between behavior (body) and cognitive events (mind); they were interested in the bridge itself, between the mind and the brain. The mind-body problem therefore evolved into what could more accurately be called the *mind-brain problem.* The objective here was to resolve how something material, such as the brain or nervous system, could produce something immaterial or mental, such as "thinking" or "ideas."

Initially, cognitive psychology incorporated mentalist approaches and therefore could not be regarded as being as one-sided as behaviorism with its emphasis on behavioral observation (Hergenhahn 1992:545). Cognitive psychologists maintained the importance of the physical body or brain, whether it was observable human behavior or the firing of neurons in the brain. However, it was cognitive psychologists' adherence to the belief that cognitive events existed and should be studied in the brain that separated the cognitive psychologists from other psychologists.

It was neural behavior that was clearly responsible for "thought," but the question was: how was the bridge between the brain and the mind constructed? Was it a one-way bridge or a two-way bridge? And how did it work? These were the kinds of questions that cognitive psychologists would make their duty to try to answer (Hergenhahn 1992:545). Those cognitive psychologists that were epiphenomenalists claimed that mental events were the manifestations of brain activity. Others, which could be called interactionists, believed that mental events actually affected physiology (e.g. the psychosomatic illnesses identified by Freud). In both cases, the material brain and the immaterial or idealistic mind exist and interact. Among epiphenomenalists, the material determines the ideological; among interactionists, the ideological determines the material. Regardless of the position taken by cognitive psychologists, a discovery would take place during the late 1940s that would, for many cognitive psychologists, settle the debate of the mind-body problem.

2.3.2 Using a Metaphor from Artificial Intelligence

In 1950, Alan M. Turing (1912-1954) founded the field of artificial intelligence (AI) with the development of an automatic computing engine (ACE) (Turing 1945; Ince 1992:IX-XI). Turing was involved in mechanical computation previous to the ACE, much of which would be realized in the electrical circuitry of the American ENIAC, but it was not until the ACE that his original design was recognized. The ACE was a machine that was based on how a human thinks and solves problems in steps.

Though Turing was involved in artificial intelligence research as early as the mid-1940s it was a paper that he prepared for "Mind: A Quarterly Review of Psychology and Philosophy", which most profoundly affected the field of psychology. In this paper he posed the question: "Do machines think?" and he conceived of a way of answering this question by defining *objectively* what "thinking" is (Turing 1950).

Turing proposed that in order to tell whether a machine thinks, the machine must go through a test. This hypothetical test, called the *Turing test*, involved three players: two people and a machine. One of the people took the role of interrogator while the other person and the machine were hidden from view of the interrogator, though both were able to communicate freely with the interrogator. The task of the interrogator was to determine which was the person and which was the machine by asking the machine and the person a series of questions. The answers that the machine or person gave to the interrogator provided the basis by which the interrogator decided which interviewee was the machine and which was the person. Obviously, there were certain restrictions as to the kinds of answers that could be given by the computer and machine and the person being interviewed. For example, one could not answer truthfully to the question: "Are you a human being or a machine?".

Similarly, being able to see or hear the machine or human could facilitate in determining the originator of the answer. Therefore, each player was supplied with a keyboard with an associated display and it was through this means that machine and person communicated with the interrogator (i.e. something like email). Communicating in this restricted way prevented the interrogator from guessing which subject was human by eliminating peripheral information — such as voice tone — forced the interrogator to focus on the information on which the judgment of intelligence was to be based. If, after several sessions, the interrogator could not distinguish human intelligence from artificial intelligence, then the machine was said to "think".

Interest in the mechanics of cognition or "intelligence" is a niche in cognitive science that has steadily grown ever since Alan Turing (1950) showed that memory and thinking in general could be mathematically generated from a material basis. The realization that cognition and mechanics were linked set the foundation for artificial intelligence and robotics in engineering and for an *information processing* view of the human mind in psychology. The mathematical mechanics behind information processing were later improved upon significantly by Grossberg (1967, 1970a, 1970b) and they continue to form the foundational equations for cognition in neural dynamics (Harvey 1994; Wu 2001). This, however, is subject matter for the next chapter.

2.3.3 Weak and Strong Artificial Intelligence

Since the computational approach to cognition first arose with Turing's work, there has been considerable debate about whether the Turing test suffices as a test for detecting thought. Some say that a machine that passes the Turing test does in fact have the mental attributes of human beings — that is, as long as the machine can solve the same problems and reason as well as humans can. Advocates of this school of thought are known as proponents of *strong artificial intelligence.* They believe that machines can *duplicate* human thought processes. On the other hand, some would say that just because a machine passes the Turing test does not imply that the machine actually has the same thought processes as a human. Humans can experience, dream, hallucinate, and feel. Machines, on the other hand, cannot do these things. Advocates of this school of thought are known as proponents of *weak artificial intelligence.* They believe that machines can only *imitate* human thought processes (Hergenhahn 1992:545-551).

However, the argument proceeds, the strong artificial intelligence camp is quite specific about what it defines as thinking (i.e. "intelligence"). According to Turing, thinking is the ability to answer questions in a human-like fashion, and in so doing fool a human interrogator in what has been called the Turing test. The weak artificial intelligence school, on the other hand, asserts that there is something more to thinking than fooling a human interrogator.

If there is something in human thought that a human interrogator cannot detect, then does it really matter what this "something" is? If a computer responds in the same way that any human would respond, then we must decide what, if anything, makes us think humans are so special.

2.3.4 Discussion: Strong Artificial Intelligence, Behaviorism, and the Rise of Functional Explanations of Cognition

Strong artificial intelligence proponents, as well as behaviorists and cognitive psychologists, are commonly regarded as monists, specifically materialists. However, a more accurate label for the strong artificial intelligence proponents is that they are *functionalists*.[9] Turing's hypothetical test is what really brought the functional conception of cognition to light.

In the Turing test, the main point is that cognition is determined by the function that it serves. That is, because a human and a computer that are being interviewed display the same attributes and respond in the same human-like way, they are both examples of cognition at work. The difference, however, is that one form of cognition is bound up in a human brain and the other form of cognition is bound up in the silicon circuitry of a computer.

The main idea behind functionalism is that the end justifies and therefore explains the means. In other words, cognition can come about as the result of several means, but the most critical attribute which defines cognition is its outward appearance — how it appears to people. Interestingly, the rise of functional explanations of cognition cannot solely be attributed to Turing, though he may have been the first to propose a functional view of cognition explicitly. Rather, behaviorism was arguing something similar. That is, behaviorism argued that it is the responses of people to certain stimuli which

[9] There are different kinds of functionalists, which I have divided into two camps, the weak functionalists and the strong functionalists. I discuss the distinction between these two functionalist schools in Section 3.2.3. Though the functionalism that is discussed in this section is weak functionalism, the distinction between it and strong functionalism does not need to be clarified at this stage in the thesis.

should be the focus of psychological studies, since it is only human behavior which can be observed directly, not the inner-workings of the brain. The main difference, therefore, between strong artificial intelligence and behaviorism is that whereas behaviorists gave up on the idea of explaining cognition, strong artificial intelligence proponents, using the same means of explanation (i.e. functionalism), argue that it is possible to explain cognition.

2.3.5 Discussion: Objections to Strong Artificial Intelligence

There are, of course, objections to strong artificial intelligence, and I will briefly introduce them below (Hergenhahn 1986:548-550). I will also explain why I do not accept these objections as valid objections against strong artificial intelligence — or what I will simply refer to as AI.

My views on AI are pertinent to the thesis because I, like the authors whose work I will be presenting in the next sections, am clearly of the view that cognition is substrate independent and is therefore not only capable of being duplicated in different substrates, but is capable of extending beyond the human individual, incorporating aspects of the social and natural environment. The consequences of a substrate independent cognition are far-reaching, because the notion of a substrate independent cognition is instrumental in reconstructing cognition in the archaeological record, as I demonstrate in Chapter 7.

The First Objection Against AI

The first objection against AI is that computers follow rules, whereas humans do not necessarily follow rules. The objection stipulates that human thinking is often influenced by "non-rule-like" feelings and emotions, which computers do not share with humans.

I would argue, however, that the Turing test is not a test to see if machines could feel like humans; it is a test to see if machines can think or reason like humans. As such, the Turing test accomplishes its task.

It is true that emotions and feelings can be regarded as factors that can affect the way different individuals reason, but in this case I would argue that feelings and emotions are based on rules. To be more specific, feelings and emotions are kinds of information processing (Sloman 2000:192) based on rules which are specific to the individual and which can affect — help or hinder — the ways the individual thinks.

Feelings and emotions may appear to be non-rule-like, but they can be regarded as rule-like nonetheless. The reason we are left with the impression that feelings and emotions are non-rule-like is that we interact with humans as peers, and not as their programmers. We do not know everyone's "rules" since we are not their programmers, and we therefore should not expect to know how everyone will react to a particular situation.

It should also be pointed out that, not all *displays* of emotion are necessarily unpredictable, and this means that one could potentially program a machine to respond emotionally to certain stimuli (e.g. when asked questions). After all, we humans often respond programmatically. For instance, in a chance encounter with someone you know in the street, it is not often, when asked how you are doing, that you actually respond with an elaborate summary of how you feel. Normally when asked how you are doing, you respond with an "alright." Sometimes one will respond with "good," sometimes "awful," but beyond these alternatives, very little else is said. It is a program that plays itself over and over again in daily life.

Whereas it may be true that more research needs to be conducted into the nature of emotions and feelings, the opponents to AI cannot refute the proposal that emotions and feelings can be conceived of as being rule-based.

The Second Objection to AI

The second objection is that AI lacks originality or creativity. Computers are programmed by steadfast rules to which they adhere. There is no unpredictability in AI behavior.

The "unpredictability argument" is very human-centric, and subjective, since it assumes that humans are unpredictable. But are we *that* unpredictable? As I mentioned earlier, we all frequently respond in the same ways when asked certain questions, such as: "How are you doing?". Also, behaviorally, we are quite predictable in certain circumstances. For instance, all humans will usually run out of a burning building. In both of the above examples it can easily be argued that we are programmed socially and instinctively, respectively. This same argument for the predictability of humans exists at the microscopic level as well as the macroscopic behavioral level. At the neural level, our biological neural networks are mechanistic and therefore just as predictable as an artificial reproduction of our neural networks. The research we discussed above supports this point.

Nonetheless arguing for the predictibility of humans does not refute the claim that machines are not creative. Boden (1998:23), for example, points out two kinds of human creativity: P-creativity and H-creativity. An idea "... is P-creative if the person in whose mind it arises could not have had it before; it does not matter how many times other people have already had the same idea" (1998:23). On the other hand, an idea "... is H-creative if it is P-creative *and* no one else, in all human history, has ever had it before"

(1998:23).

The claim that computers cannot be P-creative can be refuted by changing the frame of reference. The claim that computers cannot be P-creative is a completely subjective one and it assumes that a human observing an AI unit is also the programmer of the AI. Of course, there would be nothing creative about a computer you designed yourself. On the other hand, an AI that someone else designed could be programmed to be very creative to an observer, as creative as one wanted it to be. Thus, what is creative to one person is not necessarily creative to another person. The conclusion is that a simple algorithm can produce extremely P-creative results, for the computer which is running the algorithm and for any observer as long as the observer is not also the programmer.

According to the definitions provided by Boden (1998), it might be difficult to see how an AI could be H-creative, but the fact of the matter is that we have already seen AI being H-creative. AI is founded on the concept that algorithms are the basis of its mental functions, and so if we if it can be shown that algorithms can generate H-creative results then it follows that AI have the potential to be H-creative.

An example of such H-creativity occurred in the late 1950s when a meteorologist by the name of Edward Lorenz stumbled upon an algorithm which generated H-creative results (Lorenz 1963) — commonly referred to by mathematicians as *chaos*. From the perspective of Lorenz's algorithm and all algorithms, Lorenz's algorithm was being H-creative. Not only was Lorenz's algorithm being H-creative, but it was P-creative as well since there was no way that the exact same results could be reproduced by that same algorithm with different initial states. A change in the initial state of the algorithm and the algorithm would have produced entirely different results. This characteristic regarding the initial states is called *sensitivity to initial conditions* and is a feature of all nonlinear systems as well as the algorithms that are used to simulate these systems. Of course, not all algorithms have the capability to be H-creative, but the potential is certainly there in many algorithms.

To summarize, the two objections against AI that I discussed above are weak. However, there are two other strong objections, which I will only discuss in passing here, since I provide a more detailed treatment of these other two objections in the next chapter (see Section 3.5). These objections are that:

1. Computers cannot possibly display human cognitive capacities since computers do not interact with the environment.

2. Computers cannot possibly exhibit cognition, since computers are not brains; that is, the inner-workings of computers and brains are fundamentally different. Therefore, just because phenomena exhibit cognitive characteristics does not mean that they constitute cognition.

I agree with the opponents of AI who state that, at the current level of technology computers are incapable of the same cognition that is possible in human brains. The reason for this is that brains are not exactly computers, as I will discuss in the next chapter. But this is not to say that computers do not produce cognition which is in many ways like human cognition, nor does this imply that computers will never achieve the same capabilities of human brains. I also agree with the view that the physical environment (Gibson 1966:7-14; Gibson 1979) and the social environment (Gibson 1966:22-27) are critical for developing human cognition and that the environment affects individual cognition in ways that we are only beginning to understand. In this way, unless it is understood what precisely cognition is and how society and environment affect individual thought, human cognition is not likely to be duplicated by a machine. However, this does not mean that cognition *abstracted from society* cannot be duplicated in machines.

Before these objections are discussed any further, more work needs to be reviewed to elucidate *what* the process is that unleashes cognition. Therefore, I will consider these objections in Section 3.5 after I have discussed more about the nature of cognition. In Section 3.5, I treat these objections not as objections to be refuted by AI, but as constructive criticisms of the computational view of cognition, which can be used to strengthen the AI approach.

2.4 Supporting Research for a Computational Substrate Independent Cognition

The following sections present a selection of recent work that has been conducted regarding cognition. The purpose of presenting this work is to show that it supports a view of cognition as manifested in different media, and not necessarily as connected to the brain of the individual. Substrate independence is a natural consequence of a computational conception of cognition and the work that will be discussed supports a substrate independent conception of cognition.

A substrate independent cognition suggests that cognition can be conceived of as independent of the human brain (i.e. a calculator or computer), and as an extension of the individual brain (i.e. a concept referred to as *externalism*).

2.4.1 Hutchins and the Socio-Cultural Computing Machine

Hutchins (1995:354) defines culture as a cognitive process in which everyday practices and behavior are enacted inside as well as outside the brains of people. In this definition, individual cognition is only a subsystem in the larger encompassing system of culture.

Hutchins assertion is that cognitive science — because it failed to recognize culture as cognition — incorrectly placed symbols in the head of the individual. This was a mistake, and the consequence was an exaggerated emphasis on an *internalist* view of cognition, in which the influence of culture played no role.

Interestingly, Hutchins suggests that the erroneous emphasis on internalism was made early in the development of artificial intelligence when cognitive psychologists attempted to interpret the implications AI had for psychology.

The method by which Alan Turing discovered AI was through observing his own behavior while solving a mathematical problem. This was not through introspection but through actually incorporating his behavioral reflexes in solving a problem. Turing conceived of the automatic computing engine (ACE) through consciously being aware of how he, himself, solved problems via writing down, manipulating, and interpreting symbols — these symbols, of course, were on paper and therefore external to the agent doing the computing. In other words, Turing envisioned a computational machine that was able to "think" using symbols, but these symbols were external to the human brain in the form of writing. The manipulation of symbols, therefore, does not necessarily take place within the brain of an individual, but can be seen to take place outside of the brain.

According to Hutchins, it was cognitive psychologists' interpretation of

Turing's work that erroneously placed these symbols in the brain of the individual, but the symbols were never meant to be manipulated entirely within the brain to begin with. From the outset, Turing was actually creating a socio-cultural machine that incorporated the symbolic manipulation of material culture by the individual. What Turing proceeded to do, after self-consciously recording the steps he took during symbolic manipulation, was to distill the process of symbolic manipulation to the bare essentials. As a result, he realized that a computational agent was not necessary to do the manipulating. The agent could be taken out of the computational process completely, leaving only the steps for manipulating the symbols. The process of symbolic manipulation, therefore, could be abstracted from an agent and, hence, operate supra-individually.[10]

Theoretically, Hutchins' observations are compelling. They suggest that cognition is a process of symbolic manipulation that is external as much as it is internal. Defined as such, cognition arises from the interaction of the individual with the environment. In other words, cognition can manifest itself between an individual and some object in the physical environment or among any number of individuals in a society or culture. This is because, according to Hutchins, many (if not all) symbols and the manipulation of these symbols reside outside of the brain. Hutchins' observations suggest that the same models that have been used for years to model brain activity are better suited for modeling socio-cultural phenomena.

[10]In retrospect, Turing's intelligence test could be conceived of as a socio-cultural system of three individuals (i.e. interrogator, computer and human subject) operating in concert, where the interaction among interrogator, computer, and human subject functions in manipulating symbols among the agents. The agents in this scenario can be abstracted from the process leaving only a symbolic field where the agents resided.

2.4.2 Kennedy and Social Thinking from Social Interaction

Social psychologist James Kennedy (1998) analyzes various models describing the spread of culture to show that social interaction can optimize cognition. Cognition is conceived here as "structures and strategies for the management of knowledge" (Kennedy 1998:57). These structures and strategies are distributed amongst the individuals of a society, and each individual can be envisioned as having his or her own method of managing knowledge for accomplishing a task at hand. When individuals come together to interact and to share ideas, the individuals of the society converge on some optimal way of accomplishing a given task. Each person can be thought of as having a piece of the puzzle, where a piece of the puzzle is an arbitrary structure or strategy and the puzzle is finding the optimal structure(s) or strategy(ies).

Axelrod's Adaptive Culture Model (ACM): Thinking as a Social Phenomenon

To demonstrate that cognition can be conceived as a social phenomenon, Kennedy examines and extends Axelrod's (1997) discrete variable computer simulation that is used to simulate the spread of culture.[11] Axelrod's model represents the mental constructs of individuals — which can be taken to be beliefs, ideas, or methods for accomplishing certain tasks — by five-digit strings. For example, in an arbitrary simulation, the numeric string 76890 symbolically represents a mental construct in which each digit is a "feature"

[11] Axelrod's (1997) discrete model contrasts with the *particle swarm algorithm*, a continuous variable model, which can also be used to show the mutual cognitive benefits gained from social interaction (Eberhart and Kennedy 1995; Kennedy and Eberhart 1995; Kennedy 1997).

of the mental construct. As features or aspects of the mental construct change, so will the overall nature of the mental construct change in a combinatorial manner. Axelrod notes that these mental constructs, represented by strings, can also be taken to be social constructs such as community or state beliefs, but the emphasis seems to be on the individual in the simulations that follow.

Axelrod then creates a grid of these strings in which the grid is meant to represent 2-dimensional space and in which the grid coordinates of a given string reflect the physical locations of the individuals on an (x, y)-plane. Thus, adjacent strings of a given string or agent on the grid can be considered to be the neighbors of the agent.

Resemblance or similarity between individuals is the mechanism of social interaction and, hence, the mechanism for changing the construct of either of the parties involved in the social exchange. The notion that similarity is the characteristic that brings people together has been written about extensively by Latané (1981) and Moscovici (1985). Axelrod incorporates these authors' view — that individuals tend to associate with people with whom they have things in common — as a stipulation or rule in the program used to simulate social interaction.

The general rules for governing social interaction in Axelrod's program can best be summed up in three steps which are:

1. A random neighbor of an agent is chosen.

2. If the mental construct of the neighbor resembles the mental construct of the agent in one or more of its features, then either the agent or the neighbor adopts one of the features of the other.

3. If the mental construct of the neighbor is different in all of its features

from the mental construct of the agent, then no change occurs in either of the mental constructs.

The result of the simulation using the rules just specified is that clusters of certain stable strings emerge. These string clusters reflect distinct social groups containing individuals with the same mental constructs.

Kennedy's Experiments with the ACM

Axelrod's experiment is interesting in its own right, since it recognizes that culture can be conceived of as a cognitive process which operates on a social rather than a mental basis. Yet Kennedy takes Axelrod's experiments even further, utilizing Axelrod's model as a basis for seven different experiments which are variations on the simulation just described.

In the first experiment, Kennedy takes out the similarity condition in Axelrod's program. That is, the only condition stipulated for social interaction is that the individuals involved in the social interaction be neighbors. The result of the simulation was a uniform population throughout the grid; no distinct social groups formed.

In the other experiments, different criteria were introduced. Most of these criteria involved optimization conditions. In the second experiment for instance, the condition became: "if the sum of the features in the neighbor's construct is larger than the agent's construct, then interact. Otherwise do not interact". This resulted in all individuals of the population converging on the global optimum: 99999.

More interesting criteria were used in the other experiments, and the results varied in the number of optima. If more than one optimum arose in the simulation, then social groups distinguished themselves, much as they did in Axelrod's original experiment. If only one optimum occurred, then the entire population converged on it, resulting in a homogeneous population. These variations in the results of the simulations are revealing since they indicate that very simple rules can be used to evoke quite complex behavior, consistent with what is observed in society. In general, human societies have more complex rules for conducting behavior than those that were programmed, and so the diversity of human society, in terms of customs and ways of doing tasks, is not surprising.

Kennedy concludes his analysis with three key observations, which hold for cognition *or* culture.

1. The first observation is that individuals can learn how to solve problems (i.e. find the optimal way or ways of doing things) through interaction with other individuals.

2. The second observation is that individuals can be conceived of as comprising the parts in the encompassing machine, which is society. From an outside observer's standpoint, the ways in which people decide to accomplish tasks form a belief system resulting in a mosaic of different social groups.

3. The third observation is that culture, conceived of as inter-personal interactions guided by rules, can affect and indeed enhance the performance of individuals. Through interaction, different methods of doing things or, in some cases, the same method of doing things emerges from simple local interactions, the effects of which can only be perceived on a holistic supra-individual level.

Kennedy states that social thinking (i.e. cognition), for the most part, is not perceptible to the actual participants or individuals. That is, social cognition supercedes the individual. I should point out, though, that although social cognition supercedes individual cognition, I disagree with Kennedy's statement that the effects of social cognition cannot be perceived by the individual. In this thesis, I will show that there are socially induced phenomena that can be perceived by individuals and that the ability to recognize social cognition or culture in action allows individuals to make changes affected by and that affect social cognition. The ability to perceive the effects of social cognition is necessary for changing social processes involved in producing social cognition. Conversely, social cognition makes changes to us as individuals, and I discuss these points in considerable depth in Chapters 7 and 8.

2.4.3 Maris and te Boekhorst and the Supra-individual Cognition of Robots

Recent research in artificial intelligence has suggested that what I call supra-individual cognition is not limited to biological organisms but exists in artificial intelligence. This makes the study of supra-individual cognition not only an important subject matter for the social sciences and philosophy but also for engineering and computer science as well. As a result, these fields can all be helpful in shedding light on the phenomenon of supra-individual cognition. For example, with regard to engineering, the field of robotics can facilitate in placing the study of supra-individual cognition on a rigorous scientific footing. The reason for this is that in a laboratory setting, supra-individual cognitive experiments can be reproduced and superfluous factors that may affect the experiments can be easily accounted for and eliminated from the experiments.

Maris and te Boekhorst (1996) have studied the effects of building heaps of Styrofoam cubes using autonomous mobile robots called didabots. Heap building behavior can be used to shed light on supra-individual cognition in many organisms. Because of the simplicity of the programs each of the didabots was equipped with in the experiment, the experiment probably more closely resembles the behavior witnessed in groups of honey bees and ants (Camazine 1983; Deneubourgh, Aron, Goss, and Pasteels 1983) than it resembles human groups.

The six-wheeled didabots used in the study were equipped with five infrared sensors. Two sensors were placed on both sides of the didabot over the wheels, and the fifth sensor was placed in the rear of the vehicle. The didabots were programmed with only one rule, which was to avoid obstacles that were detected by the infrared sensors. If the sensors detected an obstacle, whether a wall or a Styrofoam cube, the didabot would turn away from the obstacle. Clearly, the front of the didabot was used to push the cubes into heaps, since the didabot was lacking sensors in the front and therefore never avoided a cube on that side.

Several experiments were conducted varying both the number of cubes (12 cubes or 25 cubes) and the number of didabots (one, three, four, or five didabots). The results showed that large single heaps did not emerge in experiments using only one didabot, but single heaps did emerge when more didabots were used. The heap-building process decreased however when more than four didabots were used, due to mutual avoidance movements.

Interestingly, this research has shown that robots can exploit their simple structure by being part of a collective in which nonlinear effects of group behavior have the effect of enhancing the heap-building capacities of individuals. Maris and te Boekhorst propose that the results of their didabot experiments are due to nonlinear effects in the collective of robots as a whole. That is, what is being observed in the heap-building process is a form of supra-individual cognition incorporating all of the didabots, not a process which only functions to enhance the individual intelligences of the robots. This notion of cognition — which operates on a different level from individual cognition, though it utilizes the individual cognitive capacities of the didabots — is not incompatible with Kennedy's (1998) and Hutchins' (1995) work, as well as with the work of others who I will discuss in the forthcoming sections.

2.4.4 Donald and the Evolutionary Import of Extended Cognition

Extended cognition subsumes individual and environment, and as such it can be seen to constitute a form of cognition which is relatively substrate independent, requiring only that a human subject is present. Extended cognition plays an important role in cognitive evolutionary research and I will discuss this research next.

In "Origins of the Modern Mind", Donald (1991) traces the evolution of cognition from our early australopithecine ancestors to modern *Homo sapiens sapiens.* Donald considers archaeological evidence along with psychological and neuro-physiological data from humans and apes.

Using the ape brain as an approximation of the brain of early australopithecus, Donald is able to trace the neuro-physiological changes which likely took place in the human brain, since the time we separated from our common ancestor with the ape some five million years ago. This data is supplemented by physical anthropological studies on encephalization and other anatomical growth tendencies, collected from the skeletal remains of *Australopithecus afarensis*, *Homo habilis*, *Homo erectus*, and *Homo sapiens.* Of more use, it seems, is the information gathered from psychological studies conducted on ape cognitive abilities. These data seem to be vital for Donald in explaining the early changes which took place in the evolution of human cognition. The archaeological data are only brought in later to support the emergence of an evolutionary stage, which occurs much later in the development of human cognition.

Taking all of this information together, Donald proposes that humans went through four cognitive stages characterized by four cultures: *episodic culture*, *mimetic culture*, *mythic culture*, and *theoretic culture*. These cognitive stages are then separated by three transition periods: the transition from *episodic culture to the mimetic culture*, the transition from *mimetic culture to mythic culture*, and the transition from *mythic culture to theoretic culture*. I will briefly summarize the highlights of each culture, focusing on theoretic culture, in particular, and its reliance on external memory.

Episodic Culture

Episodic culture is a form of mind that is attributed to early australopithecus. Because apes are presumed to be similar to early australopithecus, apes are studied extensively to understand their cognitive capacities in the hope of shedding light on australopithecine cognitive capacities. What is revealed is that apes, particularly chimpanzees, have many of the same cognitive attributes as humans, such as self-representation (i.e. an early form of consciousness) and the ability to use symbols to communicate.

Self-representation is the ability to envision oneself and is tested in several ways, but the most common test, though it is debatable, is to determine whether the subject recognizes himself in a mirror.

Use of symbolic communication, on the other hand, though it is not apparent in the wild, can be taught to chimpanzees. Chimpanzees have the ability to communicate with humans using a very simple form of sign language, but they have difficulty in inventing new words, and their capacity for putting together sentences does not extend beyond a few words. Their ability for learning sign language is a virtue of their procedural and episodic mental capacities, but their inability to communicate in chains of thought is likely due to the absence or near absence of semantic memory.[12]

Mimetic Culture

The mimetic culture, of which the likely beneficiaries were *Homo erectus*, is indirectly inferred since there is no direct evidence for this stage, such as that gathered on episodic culture through studying apes. But it appears to Donald that mimetic culture is the missing link between australopithecine cognitive capacity and human cognitive capacities and is characterized by a mind that lies between the episodic mind and the linguistic mind.

According to Donald, the invention of language did not develop abruptly and there had to have been an intermediary phase which Donald defines as mimetic. The main defense for this pre-linguistic phase is the observation of vestiges of this thought in humans who have had all linguistic capacities erased. Brother John is a classic example of such an individual who was still able to function as a whole individual in many respects but, of course, without language.

Human subjects like Brother John depended on mimesis to communicate. The fact that individuals like Brother John exist, who are able to communicate but who lack linguistic capabilities, and yet are completely conscious

[12]Semantic memory consists of impersonal information such as general concepts which are socially agreed upon. This is different than episodic memory which consists of personal information such as the knowledge of how someone is related to someone else. Semantic and episodic memory will be discussed further in Section 8.1.1.

of their actions — as they remember events after they have happened — indicates that language is not essential for functioning in society.

Mimetic culture presumably developed in two phases, a prosadic phase and a phonetic phase. In the prosadic phase, facial and postural gestures would have been an important way of communicating with others, and in the phonetic phase, auditory inflections (e.g. grunts, and sighs) would have been used. The phonetic phase would have led to the next stage in cognitive development, mythic culture.

Mimetic culture was likely characterized by conscious or intentional communication with peers, tool-making, and possibly rudimentary exchange.

Mythic Culture

Mythic culture is defined by an expansion of semantic memory, that is, memory that is useful for putting events together into a cohesive picture. Whereas the semantic side of cognition began to develop in the mimetic cultural phase, the mimetic mind was still primarily concerned with single events or episodes. The more holistic form of thinking which occurred in the mythic phase is presumed to have developed as the result of the need to describe the world in a clearer way (this was achieved by myths).

All objects such as trees, rocks, lakes, were given context in myth. These myths were narratives that were explanations of the origins of objects as well as associations of these objects with other objects in the world. In order to communicate these mythic conceptions of the world, which relied on retaining longer chain symbols, a more adequate apparatus for mythic representation evolved.

The apparatus that emerged was language, and it was preceded by phonetic mimesis. The mythic mind was a social or collective mind and it tied people together more cohesively than did the previous cognitive stages. Language, in response to the needs of the semantic mind, followed as a natural course, especially since at this time the vocal tract had evolved to a point that permitted many different vocalizations and expanded the arsenal of symbolic cues that could be utilized.

Theoretic Culture

Each mode of cognition that was evolutionarily acquired never disappeared completely, for as Donald mentions, vestiges of past modes of cognition can be found in modern humans. These vestiges act as back-up systems if the most recent modes of cognition (i.e. mythic mind and theoretic mind) are impaired. In these instances, Donald of course refers to subjects that either have not been taught a language or else have been the victims of some trauma to those regions of the brain that are associated with language. The result of cognitive development, therefore, is more accurately described as layers of cognitive modes rather than a single modern cognitive mode which was adaptively selected at the expense of all the previous cognitive modes.

Theoretic culture is a form of mind characterized by analytic thought, which emerged in response to having to build on other peoples' work. Mythic culture depended on an oral means for narrating, and this was the impetus for the development of biological changes such as semantic memory. In contrast to mythic culture, theoretic culture was externally encoded. The need to produce *theory*, whether it was in the form of governmental legislation in early complex societies or whether it was proving a mathematical theorem, resulted in various external ways of storing symbols (recall Hutchins evaluation of Turing in Section 2.4.1).

These external ways of building theory are called *external symbolic stor-*

age. The writing down of one's thoughts, for example, is external storage and the invention of writing or a system such as *quipu* was a response to the demands of theorizing in an effective way. This phase of development can also be noted in ancient Maya culture. An extremely effective writing system was devised and this resulted in advancing other fields, particularly mathematics and astronomy. This is not to say that analytical, scientific, and logical thought are the only kinds of thought that can be externally encoded, for in fact narratives can be written down as well. However, mythic culture could rely on oral narration more easily than could theoretic culture, which depended and still depends extensively on external storage devices.

Donald calls the *records* of representations (i.e. ideas) stored in the external devices, *exograms* and those stored in biological memory, *engrams* (Donald 1991:314-315). The substrate that exograms are stored in preserves exograms for a potentially unlimited length of time. Engrams, on the other hand, are stored in the nervous system, a substrate that only functions within the lifespan of the individual. What this means is that engrams disappear when the individual expires.[13] It could be said that exograms are *phylogenetic* records whereas engrams are *ontogenetic* records.

There are potentially hundreds if not thousands of external storage devices that modern humans use according to Donald. Some examples of external storage devices of which Donald speaks are: pen and paper, paint brush and canvas, calculator, and computer. This can be even further extended to include ritual (Donald 1991) and exchange (Strathern 1998). However, if we do accept that ritual and exchange are external cognitive extensions,

[13] Although the engram disappears with the death of the individual, it should be pointed out that the representation that the engram recorded may exist in other engrams in other individuals.

then Donald's chronology of events for the evolution of cognition must be revamped. For example, archaeological evidence for ritual dates to Donald's mimetic and mythic cultural phases and this means that external storage was not unique to *homo sapiens sapiens*, but may have existed as far back as *homo erectus* (Donald 1991:277).

The most important point that Donald's work has for my thesis is his view of cognition in general. His work suggests that external storage is not simply an add-on to biological cognition. He instead envisions a form of cognition that encompasses both the individual and the form of external storage that the individual utilizes.

2.5 Conclusion: Substrate Independent Computational Cognition

At first it was presumed that the human brain and the neurons that comprise it had some innate potential for cognition, but the notion that cognition was a functional phenomenon and therefore substrate independent changed all that.

Cognition is regarded in this chapter to be computational and therefore algorithmic in nature. The origin of this view should be credited to Hegel, who saw cognition in this way, but his view was soon overtaken by a view that cognition was contained within the brain. Experimental psychologists and physiologists were behind the view that cognition resided in the brain, but further studies revealed that the brain could not be the only generator of cognition.

The idea that neurons could function computationally and could accomplish quite complex tasks when joined to form networks was eventually realized in the work of McCulloch and Pitts (1943) and Hebb (1949). At the same time, the artificial intelligence research of Turing (1945, 1950) showed that cognition could be regarded as computation, a functional phenomenon, and this allows cognition to manifest itself in different substrates. From this it could be inferred that networks, whether they are in the form of actual nerve cells or algorithms, could process information in a sequential manner. It was the structure of the interconnected neurons and the way in which neurons *symbolically* interacted that was the basis for cognition, not some innate quality that neurons had that no other substrate could duplicate. The construction of artificial neural networks using silicon instead of "real" neurons is evidence of this (Churchland and Sejnowski 1992:416-418).

Physiologists and experimental psychologists sought cognition in the brain and the individual, respectively. The result was the discovery of the principles behind cognition. These principles now suggest that cognition can occur outside of the individual not only artificially, but naturally as well (i.e. in society). Cognition, therefore, does not reside solely within the head of an individual to be studied by psychologists and neuro-physiologists. Nor does cognition only reside in its artificial reconstruction by engineers and computer scientists. Cognition subsumes both the individual and the many artificial devices that the individual can utilize to enhance biological cognition. It also resides among groups of individuals and manifests itself in the everyday actions of human beings to be studied by anthropologists, sociologists, economists, and archaeologists.

Chapter 3

Cognition as a Dynamical System

Thus far, I have described cognition as a form of computation and hence capable of existing beyond a human's nervous system. Can cognition be anything else but computation? And if it can, does the re-conceptualization destroy the argument for substrate independent cognition?

Recent work has suggested that cognition has a closer resemblance to a *dynamical system* rather than to a computational algorithm (van Gelder 1995). A dynamical system is a set of functionally interconnected components which operate together in *real time*, whereas computation is a sequence of operative procedures that are interconnected, each procedure operating in its own distinct time frame.

A crucial distinction between the computational approach and the dynamical approach is that in the computational approach the material components of the computer responsible for generating cognition are related to each other *symbolically*, whereas the material components of the dynamical system responsible for generating cognition are related to each other *function-*

ally. The computational view of cognition refers to the idea that cognition is algorithmic, consisting of a sequence of procedures that are engaged as soon as preceding procedures have completed their tasks. The term computation comes from the manner in which computers operate, but this does not mean that this is the only way in which information can be processed. These procedures do not necessarily have to be engaged sequentially in a piecemeal fashion. They can be engaged simultaneously as interconnected components and as such can process information as a whole system — as a dynamical system.

My purpose in this chapter is to revamp the computational model of cognition which was discussed in Chapter 2. In line with current research, I argue for a dynamical systems conceptualization of cognition. As it turns out, such a view of cognition supports many of the same points that have been made with regard to a computational approach to cognition. For example, the view that cognition is a dynamical system supports a substrate independent form of cognition just as the computational model of cognition did. Thus, the main thread which ran through the previous chapter remains intact through this chapter.

To commence this chapter, I begin with the work of van Gelder (1995), who explains what the difference is between computation and a dynamical system and how cognition can be conceptualized as a dynamical system. To explain what a dynamical system is, van Gelder draws the reader into the field of *mechanics.*

I, too, feel that mechanics is an adequate way to ground the abstract notion of a dynamical system for the reader who is unfamiliar with the concept. I, therefore, encourage the reader to follow me in this summary of van Gelder's explanation of the distinctions between computation and dynamical systems.

3.1 Van Gelder and Cognition as a Dynamical System

Van Gelder (1995) begins his essay on "What Might Cognition Be, If Not Computation?" by discussing an engineering problem which presented itself in the late 1700s. The engineering problem was known as the governing problem.

During the beginning of the industrial revolution, steam became the foreseeable power source for the upcoming generations. However, there was one problem standing in the way, and this was how to translate the oscillatory action of the steam piston into the steady rotary action of a flywheel, which was essential in almost all machinery, such as the cotton gin or the steam engines of trains and boats. As can be imagined, the rotary action had to be a steady rotation that was not directly affected by the jerky movements of the steam piston which might be accentuated by sudden changes in the steam pressure of the boilers. Sudden lurching on a train or boat could lead to obvious passenger discomfiture or injury as well as lead to eventual problems with the structural integrity of the train or boat.

3.1.1 The Computational Governor

One way to solve this problem, and the way which would be familiar to many engineers today, would be to devise an algorithm that could control the rotational velocity of the flywheel. A contemporary solution to the governing problem, therefore, might look something like this (van Gelder 1995:348):

1. Measure the rotational velocity of the flywheel.

2. Compute the result between the desired velocity and the actual velocity of the flywheel.

3. If there is zero discrepancy, return to step one; otherwise adjust the throttle valve to effect a change in steam pressure that can compensate for the discrepancy.

4. Return to step one.

This is a standard computational approach to the governing problem and each step would be applied to the steam engine sequentially. That is, it would take time for each step to be realized mechanically. For instance, there would be a device to measure the discrepancy between desired and actual steam pressure, a device to compute the discrepancy between actual and desired rotational velocity of the flywheel, and a device that would manipulate the throttle valve; and each of these devices would take a definite amount of time to complete the associated task. Since a certain amount of time passes between the rotational velocity measurement and the change that is effected to the throttle, the computational method does not effect control of the steam engine instantaneously (i.e. in time with the steam engine).

3.1.2 The Centrifugal Governor

In the late eighteenth century, the sort of computational technology that was just proposed to solve the governing problem was not yet available and so a different means was used to smooth out the motion of the flywheel so that its rotational velocity was uniform. The problem was solved by a Scottish engineer named James Watt.

Watt devised a mechanism called a *governor*, that consisted of two weighted arms attached by hinges to the vertical axis of a horizontally rotating flywheel. The weighted arms, which were attached to the axis, were connected to another lever that controlled the throttle valve, which in turn, controlled the release of steam from the boiler.

Constructed in this manner, when the arms of the centrifugal governor rise, the throttle valve closes off the steam and when the arms return to their resting positions, the throttle is opened and more steam is injected into the engine. Thus, as a sudden increase in steam from the boiler occurs, the weighted arms that are attached to the axis lift up due to the centrifugal force caused by the increased rotational velocity (i.e., acceleration). As the arms rise, the throttle valve gradually restricts the flow of steam, and as the amount of steam continuously drops, the weighted arms gradually drop due to the decrease in rotational velocity. As the arms drop, the throttle valve is reopened to allow more steam to flow through, hence, increasing the rotational velocity to a steady level.

In this way, the centrifugal governor solved the problem of smoothing out the rotational velocity of the flywheel in a elegant and concise manner. A point that should not be lost in the description of Watt's invention is that the *centrifugal governor*, as it came to be known, worked continuously, not periodically like the computational governor did. As a result, the centrifugal governor was deemed perfect in all respects and indeed better than the computational governor.

3.1.3 Comparing the Governors

When compared, both governors, the modern computational governor and the old-fashioned centrifugal governor, are acceptable[1] control mechanisms. There are, however, very interesting differences between the two governors.

The computational governor includes several devices, each device designated a specific job. Van Gelder refers to this distribution of the workload among several different devices designed for specific tasks, *homuncularity.* In the computational governor, there is a device used to measure the actual velocity, a device used to compute the difference between actual and desired velocity, and a device that opens or closes the throttle valve relative to the difference between the actual and desired velocity. In the computational governor, each device produces a representation that *means* something to the next device in the task sequence. In other words, all the devices are symbolically connected, since each device communicates with the adjacent device through symbolism. For example, the measurement of actual rotational velocity is a symbol which means something to the computing device, since the computing device uses the measurement by subtracting it from the desired rotational velocity to obtain the discrepancy of the velocities. This discrepancy, then, is a symbol for the device that opens or closes the throttle valve, and so on. This process is cyclical, each device in the computational governor *transmitting* a representation that has some meaning for the next device in use.

The centrifugal governor, in contrast, does not operate through a chain of signification. There are no devices that are each designated to do a certain

[1]The acceptability of the computational governor depends, of course, on the rate at which the rotational velocity of the flywheel is measured or sampled. Clearly, a small sample time is more acceptable than a large sample time.

part of the workload. Rather the centrifugal governor was built to accomplish the task of controlling the flywheel velocity as a *whole* construction. There is no sequence involved in the centrifugal governor, since the arms raise automatically as the rotational velocity increases, and the arms lower when the rotational velocity decreases. The fact that the computational governor is symbolically grounded whereas the centrifugal governor is not seems to stem from an issue of *time*.

In fact, the main difference between the two governors seems to be that the computational governor assumes a different time frame than the real-time frame in which the steam engine operates, whereas the centrifugal governor assumes the same time frame within which the steam engine operates. In other words, the time frames for the computational governor and the steam engine are not synchronous, since the computational governor always lags behind the steam engine; therefore, the computational governor's time frame is not in real time with the steam engine. The computational governor operates according to its own time frame (van Gelder 1995:354). In contrast, the time frames for the centrifugal governor and the steam engine are synchronous, both operating in real time together.

The role that time plays in both governors is important not only because an engineer may or may not want a governor in synchronization with the steam engine, but it seems that representations or symbols, in general, can only be created if there is time for them to be formed. In the case of the computational governor, time separates each step in the algorithm so that one device has time to represent something to the next device in the sequence. Symbols clearly cannot form when no time for development is permitted, as is the case with the centrifugal governor. In a way, this analysis agrees with the work of Rene Thom (1973), whose work is relevant because it deals specifically with how symbols arise.

It has been proposed by the mathematician and semiotician, Thom (1973), that the creation of signs is not a straightforward process. He has proposed that objects become symbolic of something by becoming impressions upon a receptive or "plastic" medium. The medium upon which this impression is imprinted functions as a kind of "memory" for the sign. This sign-building process is one which takes time — time to be formed and time to be forgotten. Without time it would be difficult to conceive of how a representation could be formed.

To summarize, the main difference between the two governors is that the computational governor consists of parts that communicate with one another through symbolism and the centrifugal governor does not. The centrifugal governor is a system of parts but these parts function together as a *dynamical system*; they do not communicate with each other. This seems to stem from different conceptions of temporality. The computational governor operates on a time frame independent of the steam engine it is supposed to control, whereas the centrifugal governor operates in the same time frame as the steam engine it is controlling. Both are valid governors, but are built on two different conceptual frameworks.

3.2 Cognition as a Dynamical System Versus Computation

Though it could be argued that the governors discussed have the capacity to generate cognition in their own right, (i.e. the governors constitute control mechanisms that "know" what to do when to do it), van Gelder is more concerned with using the governors as examples of two different kinds of conceptual frameworks — one which is computational and the other which is dynamical — that can achieve similar tasks. The governor discussion therefore serves to illustrate how we can conceive of cognition as a dynamical system rather than a form of computation.

Cognition is normally considered to be computational, but it can also be regarded as operating on the same premises as the centrifugal governor. By "computation" van Gelder means a procedure by which rules are either instantiated or bypassed; this often takes the form of an algorithm or computer program, hence, the term computation. However, computation is only one way to process information. Dynamical systems can achieve the same results on a more naturalistic basis. That is, cognition can be conceived of as a dynamical system just like the centrifugal governor. Indeed, current research supports the view that cognition constitutes a dynamical system (van Gelder and Port 1995:10-11).

Algorithmic processing is archetypal computation and it is, therefore, the kind of processing that many psychologists and neuro-physiologists envision cognition as being. Hence, the computational mind that has so far been discussed has been seen as algorithmic, rather than dynamical. The most common form of algorithmic processing involves following a sequence of rules or conditions. If a condition is met, processing continues to the next condition in the sequence. If the condition is not satisfied then processing resorts to a subprogram until the condition is met. This subprogram often consists of an iterative procedure, called a loop, which operates until the condition is satisfied.

As with the computational governor, the notion of time when applying the computational paradigm is depicted as a discrete symbolic sequence. Therefore, though the computational paradigm is ideal for approximation, it abstracts the phenomenon being modeled from real time. In essence, any computational model operates on a time frame independent of real time and therefore does not accurately portray the phenomenon being studied.[2]

Dynamical processing, on the other hand, is a slightly newer idea than algorithmic processing in terms of its application to cognition, and it occurs in dynamical systems. It was not until the 1960s that dynamical processing was used to represent cognitive processes in the work of Stephen Grossberg (1967). Dynamical systems do not process information in discrete steps sequentially; they instead process information in continuous real-time, in which all parts of the system function simultaneously. It places the phenomenon being studied *in time* rather than something in which time is only implicitly featured. Many systems in the real world operate in a dynamical manner and cognition is no exception. Neurons interact with each other in real-time circumstances, and as such are frequently more accurately described by a dynamical format (Donald 2001; van Gelder 1995). Extended cognition, in general, operates more accurately as a dynamical system as will be discussed in subsequent sections.

I will next look at two ways in which dynamical systems can be described.

3.2.1 Describing Dynamical Systems with Maps and Differential Equations

Mathematically, dynamical systems can be modeled using maps or differential equations. Nevertheless, it should be pointed out that differential equations

[2]To illustrate algorithmic processing in more detail the reader should recall my earlier discussion in Section 2.1.2. There I talked of a procedure adapted from the Intermediate Value Theorem, which was used to find the roots of functions. That procedure can be regarded as a computational algorithm.

model dynamical systems more accurately than maps do, since real time is featured explicitly in differential equations and not in maps.

Maps and *differential equations* utilize two main symbolic variants to describe dynamical systems, parameters and variables. The *parameters* in maps and differential equations describe the dynamical system's *constraints* and are used to express constants structuring the dynamical system that is being studied. The *variables* in maps and differential equations describe the dynamical system's *states* and are used to express aspects of the dynamical system that change through time.

Example 1: Map

$$x_{n+1} = ax_n$$

Here, a is a constant coefficient or a *parameter* representing the constraint on the dynamical system that the map describes. x_n is a variable describing the state of the dynamical system. x_n varies in such a way that x_{n+1} is continuously fed back into x_n, where it is multiplied by a. Thus, this dynamical system generates a trajectory described by the sequence $\{ax_0, a^2x_0, a^3x_0, ...\}$, where x_0 is called an *initial condition* since it represents the starting state of the dynamical system. Because the initial condition is constant it functions in the same way that parameters do; that is, it constitutes yet another kind of constraint for the dynamical system.

Example 2: Differential Equation

$$\frac{dx(t)}{dt} = ax(t)$$

Here, a is a constant coefficient or *parameter* representing the constraint on the dynamical system that the differential equation describes. x is a variable describing the state of the dynamical system. x varies with respect to *real* time, t, expressed by some unit of time such as seconds or years. In this way, the variable x is said to be time-dependent (i.e. situated in real time) and is written as $x(t)$ and read as "x as a *function* of t". Though, $x(t)$ varies through time, the variable has to have a value at which it starts to vary (e.g. when $t = 0$) called an *initial condition* and written as $x(0)$. Because the initial condition is constant it functions in the same way that parameters do; that is, it constitutes yet another kind of constraint for the dynamical system.

A *map*, is a *function* or *mapping*, which takes a number, conducts one or several mathematical operations on it and outputs a corresponding number. The number that is outputted, then, is reentered as an input to the function and a subsequent number is outputted, which is then substituted into the function again. This process is reiterated indefinitely. If the process asymptotically converges to a certain number, we say that the procedure *stabilizes* and that it has a *limit*. For example, the dynamical system described in *Example 1* will converge to an equilibrium of zero, thus constituting a stable system, if $a < 1$.[3] Sometimes, however, this process does not converge, but diverges instead (e.g. if $a > 1$). In these circumstances, we say that the system is *unstable* and therefore does not have an associated limit. Maps are iterations that are used to model systems moving through time, where the current state of the system is a function of the previous state. Maps adequately describe the evolution of systems, but time is only implicitly featured. If all of the points that are outputted from the function are plotted, the result is a *trajectory* or *orbit* of the dynamical system.

In general, maps are used by mathematicians to facilitate the study of a

[3]The dynamical system could also converge to an equilibrium of x_0 if $a = 1$.

more accurate way of modeling dynamical systems called *differential equations.* Whereas maps express a state as a function of the previous state, differential equations express the *rate of change* of the current state as a function of the current state. Therefore, *real* time is featured explicitly in the rate of change term, which maps neglect to feature. As a result, differential equations model dynamical systems in a more true-to-life way than maps. In a sense, although maps model dynamical systems, the means by which they accomplish this is computational in nature, because they are updated in a discrete fashion. Since maps update in a discrete fashion rather than continuously, differential equations will be considered to be a more accurate means of representing dynamical systems throughout the rest of this thesis. Differential equations are more accurate than maps for modeling dynamical systems, not only in terms of conceptual purity, but in terms of practical difference. Modeling the same dynamical system using differential equations and maps can yield different results.

Differential equations are analyzed for stability by mathematicians in the same way that maps are analyzed for stability. Like the map of the dynamical system in *Example 1*, the dynamical system described by the differential equation in *Example 2* will converge to an equilibrium of zero, thus constituting a stable system. However, unlike the dynamical system described by the map, the condition for stability for the dynamical system described by the differential equation is $a \leq 0$. Sometimes the dynamical system does not converge, but diverges instead (e.g. if $a > 0$). In these circumstances, we say that the system is *unstable* and therefore does not have an associated limit.

More complex models of dynamical systems that can be used in archaeology are analyzed in Abramiuk (1999).

3.2.2 Connectionism and the Properties of Parallel Distributed Networks

The connectionist view of cognition (McClelland and Rumelhart 1986), which remains such an important part of psychology in explaining how learning and recalling occur, is typically a derivative of a dynamical systems approach (van Gelder 1995:374) and is based on Hebbian learning. Hebb (1949) postulated that a neuron that repeatedly fires or activates another neuron will have increased its capacity to do so and that the bonds between the neurons will strengthen as a result.

Connectionism, also known as *parallel distributed networks (PDN)* (McClelland and Rumelhart 1986), explains the concept of learning as the strengthening of bonds between certain neurons and the relaxing of bonds between other neurons. There are two kinds of connectionist approaches: local connectionism and global connectionism (Reisberg 1997:292-299).

Local connectionism is a connectionist view that allocates an entire representation to each neuron. Thus, for example, when one is engaged in the process of learning that "dice are black and white," a neuron representing "dice" will strengthen its bonds with the neurons that represent "black" and "white." Concomitantly, the neuron representing "dice" will relax its bonds with any neurons that represent other colors. In this way, dice are not thought of as blue or red, but only as black and white.

Global connectionism is a connectionist view that distributes representation among many neurons. This time, several neurons, when activated, represent "dice" and two other groups of neurons represent "black" and "white". Thus, when one is engaged in the process of learning that "dice are black and white", the bonds among the neurons representing "dice", "black", and "white" will be strengthened. Concomitantly, the bonds with neurons representing other colors will be relaxed, so that dice are only thought of as black and white and no other colors. The global case is currently regarded as being a more accurate depiction of learning than the local connectionist approach.

In the local connectionist approach, each neuron is designated a certain task, which is to play the role of a representation and strengthen the associated bonds with other neurons designating other representations. Under the local connectionist umbrella, neurons bond with each other to form more complex representations. This method of representation is *structuralist*, since complex representations are constructed in a piecemeal fashion with constituent representations.

In the global connectionist approach, on the other hand, the representation does not form until processing is completed — that is, when all neurons have interacted and have reached a steady state. This is because it is only after all the appropriate neurons have bonded that a representation, *which is greater than the sum of its parts*, emerges. A unique feature of global connectionism is its capacity to form a complex representation without having to resort to intermediary steps, which is a *Gestaltist* way of viewing cognition (versus a structuralist way of viewing cognition). That is, the entire complex representation is perceived all at once and the details that make up the representation are noticed later.

The connectionist approach is generally regarded to be a dynamical way of viewing neural interaction and emergent cognition, rather than a computational way, since the strengthening of bonds between neurons constitutes a dynamical system in which all neurons involved in the interaction are working together as an organic whole. This process in which neurons work together as a system more closely resembles how an organ such as the brain would function, making the dynamical system a more adequate means of explaining the emergence of human cognition than is possible with an algorithm.

For duplicating cognition, dynamical PDNs have one other interesting property which make them preferable over computation. Dynamical PDNs are autonomous *self-organizing* systems and this is how we conceive of cognition. By being autonomous and self-organizing, dynamical PDNs have some degree of *executive control*[4] over their systemic functioning and over the output they produce. That is, in a sense, any experiences that these networks may be presented with are "owned" by them (Donald 2001:155-156). These characteristics taken together constitute a rudimentary kind of *consciousness*,[5] and the degree to which PDNs self-organize and "own" their experiences "determines how much conscious capacity we are willing to attribute to them" (Donald 2001:156).

The emerging phenomenon of executive control generated by PDNs resembles consciousness in another important respect. Consciousness, according to Donald (2001), is a *domain-general* phenomenon in that it does not appear to have a specific location within the brain. Executive control, like consciousness, lacks a control center and is instead a property that is distributed throughout the network, emerging from the whole network rather than from a constituent or node within the network (Reisberg 1997). Specifically, distributed executive control is a property of recurrent networks as I have already discussed in Section 2.2.2.

To summarize, connectionism does have elements that makes it, in some

[4]Executive control is the capability of a system to control aspects of its own functioning (Donald 2001:155-156) and for this control to be distributed (Reisberg 1997:295-299).

[5]I prefer to use the term executive control rather than consciousness; however, when I do use the term consciousness I refer to *psychological consciousness* rather than to *phenomenal consciousness* as it is used by Chalmers (1996). Section 3.4.2 discusses the different interpretations of consciousness in more depth.

cases, computational, but it is generally accepted to be dynamical (van Gelder 1995:369-371). With the recent inclination toward parallel distribution and global representation (McClelland and Rumelhart 1986), it seems that dynamical systems more accurately reflect cognitive capacities than computation does.

3.2.3 Computation, Dynamical Systems, and Weak and Strong Functionalism

In light of van Gelder's discussion regarding the distinction between the computational view of cognition and the dynamical view of cognition, another crucial distinction can be made between the computational and dynamical approaches. From a philosophical standpoint, both the computational approach as well as the dynamical approach are functional approaches.[6] The difference, however, is that the computational approach is a *weak* variety of functionalism (recall I discussed this kind of functionalism in Section 2.3.4), whereas the dynamical approach is a *strong* variety of functionalism.[7]

Weak Functionalism

Weak functionalism is more concerned with the *end* result of a process. It is more concerned about the outward appearance of the phenomenon be-

[6]It is important to note that the way *weak* functionalism is used in this thesis is consistent with the way psychologists and philosophers of mind define functionalism rather than the way anthropologists and archaeologists define functionalism. See Mautner (2000:212-213) for an explanation of this distinction.

[7]In Section 3.4.1, I draw on Durkheim (1933:41) and in this context it is worth noting that Durkheim made a similar distinction between what I refer to as weak and strong functionalism. Durkheim, however, does not use these terms explicitly, nor does he go into much depth on the distinction between the two varieties of functionalism.

ing studied rather than the *means* by which the phenomenon being studied actually emerged. Thus, if an artificial cognitive phenomenon is compared to a natural cognitive phenomenon and they are found to be identical, then the weak functionalists would assert that they are identical.

The computational approach epitomizes a weak functional viewpoint. Weak functionalists believe that if something serves the same purpose as something else, then they are for all intents and purposes identical. In the computational approach, weak functionalism is reflected in the way that AI advocates are more concerned with the appearances of cognition — that is, if something produces the same effects that natural cognition does, then it is cognition.

Weak functionalism is what most philosophers of mind associate with functionalism since the distinction between weak and strong functionalism is not often made. For example, a common definition of functionalism for philosophers of mind, and which I refer to here as weak functionalism, is:

> "the view that what makes a mental state what it is (an experience of pain, a desire to drink, a belief that p), is the functional role it occupies. The view is usually associated with materialism about the states that have these functional roles" (Mautner 2000:212).

What Mautner means by being associated with materialism is that functionalism in the philosophy of mind is used to overcome materialist theories of mind which would have it that mental states of the same kind need to be bound up with the same physical conditions (Mautner 2000:213). We know, of course, that such materialist explanations of cognition are not accurate since cognitive capacities can be duplicated in different substrates (e.g. organic and silicon) (Churchland and Sejnowski 1992:416-418).

Functionalism for most psychologists also conforms to a weak functional view of cognition, because in psychology, functionalism is:

> "the view that behavior and mental phenomena can be explained as an organism's strategies for adapting to its biological or social environment" (Mautner 2000:213).

In both cases, philosophers of mind and psychologists agree that a cognitive capability or mental state can best be explained by the purpose it serves in the grander scheme of things, not by the material process from which emerges.

Strong Functionalism

Strong functionalism is concerned with *means* as well as the *end* of a process. Strong functionalism is concerned about the means by which a phenomenon emerges as well as the aesthetic character of the phenomenon being produced at the end of the process. Thus, if an artificial cognitive phenomenon is compared to a natural cognitive phenomenon and they are found to be identical *and* if the properties which produce the cognitive phenomena are identical, then the strong functionalists would assert that they are identical.

The dynamical approach epitomizes a strong functional viewpoint. In the dynamical approach, this notion is reflected in the way that dynamicists are more concerned with what the process *is* by which cognition emerges. Strong functionalists therefore would disagree with the notion that if something produces the effects of cognition then it is cognition. Strong functionalists believe that if something serves the same purpose as something else, then they are *only functionally* identical; they are not truly identical until the properties underlying the phenomena being analyzed are shown to be identical.[8]

Though most philosophers and psychologists adhere to weak functional view of cognition, there are a few philosophers that diverge from this account of cognition. Block (1978) and Chalmers (1996) are both functionalists but they also note that the material basis for cognition needs to be organized in a certain way (see Section 3.4.2). That is, the role that a mental state serves is still important, but this does not by itself make that mental state cognition. Cognition emerges from certain *functional organizations* of interconnecting material components. Therefore, not only must a mental state serve a particular role, but the organization of the material basis from which the mental state emerges must be of the sort that is conducive to generating cognition in order for that mental state to be regarded as cognition.

Note that this strong functional view relies on a material basis, but it does not rely on the *type* of material the basis is made out of, and therefore cannot be regarded as materialism or physicalism. Rather strong functionalism relies on the manner in which the material basis is organized. In this way, strong functionalism, even though it seems related to materialism, still retains the attribute of substrate independence (which is also a characteristic of weak functionalism).

The distinction between the functional views in the computational and dynamical approaches has important implications for AI. One of the big arguments against AI is that the AI view is only concerned with the appearances of cognition, but adopting a dynamical approach changes the debate. Dy-

[8]The process by which the properties underlying the phenomena being studied are shown to be identical is essential for demonstrating that a phenomenon *supervenes* on a particular property. Supervenience is a concept often used in metaphysical inquiry (Chalmers 1996:33-38).

namicists, if regarded as the new generation of AI advocates, no longer need to defend their position by arguing that imitation is sufficient for cognition; they can now state that they know what cognition is — it is a dynamical system. As such, because dynamicists have a firmer grasp of what cognition *is* — a functional phenomenon capable of being described mathematically — dynamicists can assert with more confidence than old school AI advocates that cognition can indeed be duplicated in different media. This is because cognition is a dynamical system and dynamical systems are transposable.

More on how the strong functionalism of the dynamical approach can provide firmer support for a substrate independent cognition advocated by AI advocates will be discussed in Section 3.5.

3.3 Neural Dynamics

The research that was conducted by such scientists and mathematicians as McCulloch and Pitts (1943) and Grossberg (1967, 1970a, 1970b) contributed greatly to the advancement of neural and behavioral studies. As a result of their ground-breaking work, the study of *neural dynamics* was born. By the mid 1980s, other scientists (Hopfield 1982, 1984) made significant contributions to this promising new field. Since then, the study of neural dynamics has not only helped us understand how the brain functions and processes information, but it has provided us with the knowledge to construct *artificial neural dynamic networks.* Therefore, the study of neural dynamics not only impacts the field of biology, but it has implications for several disciplines including biology, engineering, computer science, and economics.

Neural dynamic networks are feedback or recurrent networks (i.e. they have bi-directional flow between the nodes) and are, therefore, capable of self-organization. In Section 2.2.2, it was discussed that these kinds of networks have memory (CAM) and, hence, the ability to recall information which was stored in the past. These dynamic networks are part of a branch of learning theory that is called the theory of *embedding fields*, and the flows of the dynamic networks obey systems of nonlinear functional differential equations (Grossberg 1970b:28).

The structure and dynamics of a neural network — the way that neurons are interconnected through time — gives the neural network the ability to learn and remember patterns. In fact, all neural dynamic networks have this information processing capability (see Section 7.1). Some neural dynamic networks, however, are better than others at such tasks, and elucidating what network form is better suited to a particular task entails a detailed analysis of the dynamics of the network.

3.3.1 Introducing Neural Dynamic Models

Neural dynamic networks are natural (i.e. biological) cognitive systems, which are modeled using differential equations. The reader should recall from Section 3.2.1 that differential equations are a means of describing dynamical systems and, hence, neural dynamic networks, since neural dynamic networks are dynamical systems. The reader should achieve a modest familiarity with the equations below, — particularly the "Rewritten Additive STM Equation" — since these equations provide a template for all cognitive systems. They are important to my argument in Chapter 7 where I discuss the general characteristics of cognitive systems.

I begin by introducing the model variables used to describe a typical biological neural interaction (Harvey 1994; Wu 2001). Let us denote n nodes, or more specifically neurons, by $\nu_1, \nu_2, ..., \nu_i, ...\nu_n$. Then:

1. The variable, x_i will describe the state, also called the *activation* of the ith neuron, ν_i. Biologically, the activation of the neuron is the change in potential from the neuron's equilibrium potential. The variable x_i is also called the *short-term memory* (STM) *trace.*

2. The term, Z_{ij}, which can also be a variable if we take plasticity into account, is the coupling strength associated with ν_i's interaction with ν_j. Biologically, Z_{ij} is the average release rate of neurotransmitter over the unit axon signal frequency. Z_{ij} is also called the *synaptic coupling coefficient* or the *long-term memory* (LTM) *trace.*

I will now construct models for these variables as they change through time.

3.3.2 The Additive STM Equation

Suppose that we have a change in the potential (activation) of the neuron from its equilibrium state. This change is often caused by internal as well as external processes. Involving time, we can easily write these processes as:

$$\frac{dx_i}{dt} = \left[\frac{dx_i}{dt}\right]_{Internal} + \left[\frac{dx_i}{dt}\right]_{External}. \tag{3.1}$$

Another neuron connected to the neuron in question, ν_i, may have either an *excitatory* effect or an *inhibitory* effect on ν_i. Other stimuli may also contribute to the excitation or inhibition of ν_i. We can write these external processes as additive processes so that

$$\left[\frac{dx_i}{dt}\right]_{External} = \left[\frac{dx_i}{dt}\right]_{excitatory} - \left[\frac{dx_i}{dt}\right]_{inhibitory} + \left[\frac{dx_i}{dt}\right]_{stimuli}.$$

Equation 3.1 can then be expanded to:

$$\frac{dx_i}{dt} = \left[\frac{dx_i}{dt}\right]_{Internal} + \left[\frac{dx_i}{dt}\right]_{excitatory} - \left[\frac{dx_i}{dt}\right]_{inhibitory} + \left[\frac{dx_i}{dt}\right]_{stimuli}. \quad (3.2)$$

Here, we assume that the internal processes of ν_i are governed by:

$$\left[\frac{dx_i}{dt}\right]_{Internal} = -A_i(x_i)x_i, \quad (3.3)$$

where $A_i(x_i) > 0$ and describes the rate of decay for ν_i. This implies that the internal processes of ν_i are exponentially decaying and are, thus, stable processes.

Next we assume that synaptic excitation is proportional to the pulse train frequency, which implies that:

$$\left[\frac{dx_i}{dt}\right]_{excitatory} = \sum_{k=1;k\neq i}^{n} S_{ki}Z_{ki}. \quad (3.4)$$

Here, S_{ki} is the average signal frequency, often referred to as the *signal function*, initiated at ν_k and evaluated at ν_i. The signal function can be defined as:

$$S_{ki}(t) = b_{ki}f[x_k(t - \tau_{ki}) - \Gamma_k], \quad (3.5)$$

where Γ_k is the threshold that ν_k must overcome in order to "fire" (emit a signal from ν_k to ν_i), τ_{ki} is the time delay involved in propagating a signal from ν_k to ν_i, b_{ki} is a nonnegative constant, and $f(\cdot)$ is a *normalized* signal function, which I will discuss below in Section 3.3.6.

For inhibitory inputs, the coupling strength is constant and so we can simply write the inhibitory processes in ν_i as:

$$\left[\frac{dx_i}{dt}\right]_{inhibitory} = \sum_{k=1;k\neq i}^{n} C_{ki}, \tag{3.6}$$

where $C_{ki} \geq 0$ and C_{ki} can be defined as a function such that:

$$C_{ki}(t) = c_{ki} f[x_k(t - \tau_{ki}) - \Gamma_k]. \tag{3.7}$$

Here, c_{ki} are nonnegative constants.

Together we may write the additive STM equation as follows:

$$\frac{dx_i}{dt} = -A_i(x_i(t))x_i(t) + \sum_{k=1;k\neq i}^{n} b_{ki} f[x_k(t-\tau_{ki})-\Gamma_k]Z_{ki}(t) - \sum_{k=1;k\neq i}^{n} c_{ki} f[x_k(t-\tau_{ki})-\Gamma_k] + I_i(t), \tag{3.8}$$

where $I_i(t)$ represents an external stimulus.

3.3.3 The Passive Delay LTM Equation

The passive delay LTM equation can be obtained directly from Hebb's Law, which states that:

$$\frac{dZ_{ij}}{dt} = -B_{ij}(Z_{ij})Z_{ij} + P_{ij}[x_j]^+, \tag{3.9}$$

where $B_{ij}(Z_{ij}) > 0$ and

$$P_{ij}(t) = d_{ij} f[x_i(t - \tau_{ij}) - \Gamma_i], \tag{3.10}$$

is a signal function like $S_{ki}(t)$ was in the additive STM equation.

Here, d_{ij} are nonnegative constants and $[x_j]^+$ is a function defined by:

$$[x_j(t)]^+ = \begin{cases} x_j & \text{if } x_j \geq 0 \\ 0 & \text{if } x_j < 0 \end{cases}$$

What this all means is that a signal P_{ij} must be sent from ν_i to ν_j at the same time that ν_j is activated (ie. $x_j > 0$) in order for Z_{ij} to increase.

Together, we may write the passive delay LTM equation as:

$$\frac{dZ_{ij}}{dt} = -B_{ij}(Z_{ij}(t))Z_{ij}(t) + d_{ij}f[x_i(t-\tau_{ij}) - \Gamma_i][x_j(t)]^+. \tag{3.11}$$

3.3.4 The Additive STM and Passive Delay LTM Equations

The STM and LTM formulations can be brought together to comprise the final system of equations:

$$\frac{dx_i}{dt} = -A_i(x_i(t))x_i(t) + \sum_{k=1;k\neq i}^{n} b_{ki}f[x_k(t-\tau_{ki})-\theta_k]Z_{ki}(t) - \sum_{k=1;k\neq i}^{n} c_{ki}f[x_k(t-\tau_{ki})-\theta_k] + I_i(t), \tag{3.12}$$

$$\frac{dZ_{ij}}{dt} = -B_{ij}(Z_{ij}(t))Z_{ij}(t) + d_{ij}f[x_i(t-\tau_{ij}) - \Gamma_i][x_j(t)]^+. \tag{3.13}$$

3.3.5 The Rewritten Additive STM Equation

The system of equations (3.12 - 3.13) can be rewritten if we assume that the LTM traces, $Z_{ij}(t)$ converge to constant values. Summing up all of the positive and negative feedback terms gives us the important equation:

$$\frac{dx_i(t)}{dt} = -A_i x_i(t) + \sum_{k=1}^{n} z_{ki} f_k(x_k(t-\tau)) + I_i(t), \tag{3.14}$$

where z_{ki} are fixed synaptic couplings, or *connection coefficients*, which I will also refer to as *interactional values* in the next section. The term τ is the time delay in the transmission of a signal from ν_k to ν_i. This term may sometimes be left out for the sake of simplicity. However, it should be noted that time delay can can drastically affect the dynamics of systems and we will consider it later.

For those that are familiar with neural dynamics, equation 3.14 without the time-delay is related to the n-dimensional Cohen-Grossberg system[9], defined by:

$$\frac{dx_i(t)}{dt} = a_i(x_i(t)) \left[b_i(x_i(t)) - \sum_{k=1}^{n} w_{ki} f_k(x_k(t)) \right], \tag{3.15}$$

$1 \leq i \leq n$, which is subject to the following conditions:

1. Symmetry of the connection matrix, $[w_{ki}]$.

2. Continuity of $a_i(x_i(t))$ for $x_i(t) \geq 0$ and $b_i(x_i(t))$ for $x_i(t) > 0$.

3. Positivity of $a_i(x_i(t))$ if $x_i(t) > 0$.

4. Monotonicity in the sense that $f_i(x_i(t))$ is continuously differentiable and $f_i'(x_i(t)) \geq 0$ for $x_i(t) \geq 0$, where $(')$ denotes differentiation.

These conditions must be fulfilled in order to use Grossberg's *Covergence Theorem.* In other words, in order for a pattern to be recalled successfully, the neural dynamic network must be *stable.* Grossberg's Covergence Theorem

[9]Note that the Cohen-Grossberg system is normally written without a time-delay, τ.

can facilitate the analyst in ascertaining whether or not the dynamical system being analyzed is indeed stable.

The relationship between equations 3.15 and 3.14, not considering the time-delay, τ, is: $a_i(x_i) = 1$, $b_i(x_i) = I_i - A_i x$, and $w_{ki} = -z_{ki}$.

3.3.6 Normalized Signal Functions

I mentioned in the previous sections dedicated to neural dynamics that neurons follow relatively simple rules described by functions, $f(\cdot)$, called normalized signal functions. This section will be dedicated to describing some common normalized signal functions that are used in neural dynamics.

- One commonly used normalized signal function is the *step function* defined by:

$$f(u) = \begin{cases} 1 & \text{if } u \geq 0 \\ 0 & \text{if } u < 0 \end{cases},$$

  where τ_{ki} is the time delay in the transmission of the signal from ν_k to ν_i. Models that use these normalized signal functions are often called McCulloch-Pitts models in recognition of the ground-breaking research conducted by McCulloch and Pitts (1943).

- The second normalized signal function that can be used is the *piecewise linear function* defined by:

$$f(u) = \begin{cases} 1 & \text{if } u \geq \frac{1}{\beta} \\ \beta u & \text{if } 0 < u < \frac{1}{\beta} \\ 0 & \text{if } u \leq 0 \end{cases},$$

where β is the *neuron gain.* Note that the piecewise linear function reduces to the step function as $\beta \longrightarrow \infty$.

- The third and most commonly used normalized signal function that can be utilized is the *sigmoid function* which can be defined as:

  $$f(u) = \frac{1}{1 + e^{-4\beta u}},$$

  where $u \in \mathbb{R}$ and β is the neural gain such that $\beta = f'(0) > 0$. Again, as with the linear piecewise function, the sigmoid function becomes the step function if we let $\beta \longrightarrow \infty$.

To summarize the above sections on neural dynamics, the dynamical systems behind the production of cognition in the central nervous system have been described. Through the study of neural dynamical systems much insight has been gained regarding the *functional*, rather than the *material*, nature of cognition. The study of neural dynamical systems have already provided scientists with models that have been used in constructing artificial cognitive systems (Churchland and Sejnowski 1992:416-418; Wu 2001:8). As a result, these dynamical systems, which have been described, can be used to provide a template for building more general cognitive systems which I focus on in Chapter 7.

3.4 Supra-Individual Cognition and Extended Cognition as Dynamical Systems

In the last chapter, cognition was conceived as computation, but because more research in recent years supports the view that cognition is a dynamical system, — in which the functional organization of the material basis plays a fundamental role — I will focus in this section on work that is closely associated with a dynamical conception of cognition.

In the last chapter, I amassed examples that are integral to conceptualizing cognition as subsuming both the individual and the environment that surrounds the individual, whether physical or social. Therefore, the notion that cognition extends beyond the individual and in some cases is detached from the individual (e.g. a calculator) should not be new to the reader. The difference in this chapter will not only be to emphasize that cognition is a dynamical system, but to be explicit about the distinction between *supra-individual* and *extended* cognition. In being explicit about this distinction, special attention will be paid to the fact that cognition can be conceived as two sorts:

1. Supra-individual cognition manifests itself as a dynamical system abstracted from the individual (i.e. body and nervous system). Supra-individual cognition can link up with individual cognition but its source is independent from that of individual cognition. Sections 3.4.1 – 3.4.2 are examples of this kind of cognition.

2. Extended cognition manifests itself as a dynamical system subsuming individual and environment. Extended cognition cannot be conceived of without including the individual, which is its source. Sections 3.4.3 – 3.4.4 are examples of this kind of cognition.

3.4.1 Durkheim and Society as a Dynamical System

Although Emile Durkheim's work (Durkheim 1933) predates the cognitive revolution, his view of society parallels the dynamical view held by cognitive science. As such, Durkheim's work can be seen to represent one of the first significant attempts to not only realize supra-individualism in social form, but to realize a sort of cognition associated with this supra-individualism.

Emile Durkheim was heavily influenced by the French and German intellectual tradition, primarily by Comte (1988) and Schäffle (1889). Comte inspired in Durkheim the positivistic notion that the study of society (sociology) is a science and that social phenomena can be studied objectively as long as the features that one is studying are explicit and therefore can be tested. Schäffle, on the other hand, provided Durkheim with the conceptual tools necessary to provide a definition of society.

Durkheim, like Schäffle and Comte, often utilized concepts from biology as metaphors for facilitating sociological analysis (e.g. Durkheim 1933:62-63) (Giddens 1971:67). Schäffle, and later Durkheim, would compare human society to an organism which lives a life distinct from the lives of the cells that compose it. The main point is that society is not the sum of the lives of a group of individuals but an entity that has properties of its own. In this sense, the whole is considered to be greater than the sum of its parts.

Society, unlike its organic analog, is not considered by Schäffle and Durkheim to be a series of parts that are united physically. Rather, society comprises individuals that are tied together by ideas (Durkheim 1933:96-110) instead of a material substrate. Society functions on a level separate from the individual, but nonetheless greatly influences the individual; in turn, the individual impacts society. This however does not mean that the individual is unhappy because he is tied to other people. Society is not a prison, and in general the individual is quite content to remain in society.

The ideas that bond individuals together and that are shared by all individuals in the society comprise the *collective conscience.* The collective conscience can be conceived of as a composite of individual minds. Each individual mind has its own view, but it is all the minds together that make up the collective conscience — separate minds working as a group. The manner in which this group mind functions is different from the manner in which an individual mind functions. This is an important point to emphasize, since it suggests that supra-individual and individual knowledge can be conceived of as forming separately. The collective conscience constitutes a system of beliefs that is shared amongst individuals of a society and which changes slowly through time *relative to the individual* (Durkheim 1933:79-82). Thus, generations pass and the collective conscience remains from one generation to the next. It therefore has a longer life span than any individual human (Durkheim 1933:80) and as such can be conceived of as operating on a different plane or at a different frequency from that of the individual mind.

The notion of collective conscience, because of the ambiguity associated with it, is quoted at length in the following passage (Durkheim 1933:79-80):

> "The totality of beliefs and sentiments common to average citizens of the same society forms a determinate system which has its own life; one may call it the collective or common conscience. No doubt, it has not a specific organ as a substratum; it is, by definition, diffuse in every reach of society. Nevertheless, it has specific characteristics which make it a distinct reality. It is, in effect, independent of the particular conditions in which individuals are placed; they pass on and it remains. It is the same in the North and in the South, in great cities and in small, in different professions. Moreover, it does not change with each generation, but on the contrary, it connects successive generations with one another. It is, thus, an entirely different thing from particular consciences,

> although it can be realized only through them. It is the psychical type of society, a type which has its properties, its conditions of existence, its mode of development, just as individual types, although in a different way."

Durkheim (1933:80) goes on to state that the collective conscience is an ambiguous term since it does not represent all of the social conscience, just the psychical aspect of the social conscience. He explains what he means later when he calls the collective conscience "sentiments". These sentiments can be considered to be morals that individuals in society share. Our feelings on severe crimes, such as murder, might be something that would constitute our collective conscience. For example, for many people, depending on the circumstances, murder is considered wrong. These same people may feel uncomfortable, sad, or angry at the thought of someone committing murder. These feelings constitute the collective conscience responding to the notion of murder.

Durkheim, emphasizes the fact that the collective conscience is our anchor, our center. He presents the abstract notion of collective conscience so that it may account for social phenomena, much like Newton introduced the abstract concept of gravity to explain why objects fall to the ground. Durkheim states that the collective conscience guides us in how we feel and eventually act. Durkheim (1933:81) states: "...we must not say that an action shocks the common conscience because it is criminal, but rather that it is criminal because it shocks the common conscience." This emphasis directs the focus of study on society rather than the amoral acts that are external to society, in the same way that gravity directed the focus of causal study on universal mechanics rather than on the specific objects that are governed by mechanics.

Durkheim thought that the collective conscience would be more apparent in less hierarchical societies. In such a society with little division of labor, individuals can more easily relate to one another since they share many of the same tasks. Therefore, individuals within less hierarchical societies should be affected by what happens to everyone else. A crime against an individual in such a society is a crime against society and it reflects itself in the kinds of criminal laws that are instituted in society. Durkheim states that a less hierarchical society is reliant on a kind of sentiment called *mechanical solidarity* (Durkheim 1933:70-110). Hierachical societies, on the other hand, are governed by a sentiment known as *organic solidarity* and tend to have more heterogeneity and a stronger sense of individuality (Durkheim 1933:111-132). Criminal laws play an important role in the analysis of these kinds of societies since they function as an *external index* for studying the different kinds of solidarity in society (Durkheim 1933:64).[10]

Discussion: Durkheim's Collective Conscience

It should be noted, however, that the notion of collective conscience is problematic. It is one thing to propose its existence, but another to detect it, even with an external index. Durkheim, himself, never completely convinced others of the empirical existence of a collective conscience. Subsequent attempts at statistically detecting it have been similarly unconvincing. For a more recent attempt at detecting collective conscience, and its subsequent rebuttal, see Kraus, Schild, and Hodge (1978) and Guppy (1982), respectively.

Durkheim's views on conscience can be extended to the concept of cogni-

[10]The notion of the external index would remain a very important methodological contribution to the social sciences. An external index is a physical trait observed in society that is used to reflect a social phenomenon that one is interested in studying.

tion, since Durkheim in many ways used the term conscience in a manner not dissimilar to how I have used the term cognition. Durkheim would have been an advocate of the view that cognition existed outside of the individual and his studies were the first attempts to place this supra-individual cognition on a rigorous footing. Durkheim was one of the first to use statistics as a way of showing that supra-individual cognition was influencing the behavior of individuals (Durkheim 1952). He showed that social beliefs correlate with the choices that individuals make and as such are subject to being analyzed sociologically rather than psychologically.

Though Durkheim proposed two kinds of cognition, individual and supra-individual (Durkheim 1933:100,105), it is supra-individual cognition which Durkheim posited as the stronger of the two (1933:100) and which he felt had the greatest foothold in the centers of the brain controlling behavior (1933:97-98). Supra-individual cognition, however, is linked by him to individual cognition and, because they occupy the same "organic substrate", form one all-encompassing cognition (1933:106).

This notion that supra-individual and individual cognition are separate phenomena yet united in some manner is not as contradictory as it may seem. Durkheim is a (strong) functionalist (Durkheim 1933:49), and as such Durkheim is able to conceive of two kinds of cognition abstracted from one another yet linked, since both individual and supra-individual cognition occupy the same "organic substrate" (1933:106) and independently serve the same fundamental purpose, which is to inform the members of a society about what is criminal and what is not criminal (1933:81). Therefore, individual cognition and supra-individual cognition, though different, are united in their fundamental purpose and in their development toward this fundamental purpose within the same "organic substrate". Even criminal acts spurred by individual cognition can be conceived of as maintaining this social gauge in that criminal acts attempt to weaken the effect of supra-individual cognition which, in turn, means that supra-individual cognition must be strengthened at all costs by the other members of society.

Durkheim saw supra-individual cognition as he saw society — as a system. Being diffused over a society meant that supra-individual cognition changed with respect to the characteristics of the society, such as the society's division of labor. Thus, like society, supra-individual cognition was envisioned as an organic whole in which all parts of the system worked together concurrently, not sequentially. That is, a change in one element brought on associated changes to all of the elements of the system, not to just a finite number of elements. Because supra-individual cognition changed through time — very slowly in some cases — it was dynamic. As such, Durkheim envisioned supra-individual cognition as a dynamical system, not as computation.

3.4.2 Chalmers and the Pervasiveness of Dynamical Systems Which Generate Cognition

Much light can be shed on the topic of cognition through an evaluation of the relationship between cognition and consciousness. This is because the conditions necessary for producing consciousness are also necessary for generating cognition (Chalmers 1996:25-26).

For Chalmers there is an important distinction between cognition and consciousness, which should be made clear from the outset in order to understand how his work sheds light on supra-individual cognition. I discuss the distinction between cognition and consciousness below.

Chalmers' Notion of Cognition

For Chalmers, cognition is a phenomenon that is easily comprehended because it is governed by and emerges from material processes. As a result, the study of cognition is regarded as a science by cognitive psychologists, neurophysiologists, computer scientists, and engineers. That is, cognition can be explained using a *reductive functional* paradigm, which implies that cognition can be explained through the systemic means by which it has arisen.

The means by which cognition arises is theorized to be a dynamical system,[11] and the dynamical system's states directly correspond to cognitive states. Within the brain, the dynamical system refers to the neurophysiological system and the cognitive states correspond directly to certain thoughts the individual may be having. In principle, the dynamical system is the "cause" of cognition and, as such, wherever the dynamical system manifests itself, the corresponding cognitive states of the system should emerge (Chalmers 1996:24). Chalmers notion of cognition as a dynamical system is based on what we have learned about the mind from the 1940s to the present, and is supported by the fact that these dynamical systems, when replicated in another environment (say silicon), reveal themselves to be intelligent as defined by Turing in 1950.

Chalmers' Notion of Consciousness

Chalmers is a dualist and his sympathy for this school of thought presents itself immediately. Chalmers is clearly bent on turning consciousness into

[11] Although Chalmers (1996:330-331) regards himself as a computationalist, computation does not figure significantly in his discussion of cognition and consciousness. Chalmers' descriptions of such concepts as *functional organization* suggest that he can be regarded as a dynamicist in the most fundamental aspects on the his theory.

something phenomenal rather than material, hence returning to the mind-body problem once again after it had been left behind with the discovery that cognition could essentially be reduced to material states by psychologists. Scientists of cognition can remain monists, claims Chalmers, but those reckless enough to consider the study of consciousness must succumb to dualism, because consciousness is forever phenomenal.

Chalmers sees two main links connecting the physical world to consciousness: the link between a physical system and cognitive states, and the link between cognitive states and conscious states (Chalmers 1996:25). To be more specific, there exists a process that generates cognition (i.e. *awareness*) from a materially based dynamical system. Another process explains how and why conscious states (i.e. *consciousness* or *experience*) are accompanied by cognitive states.

Cognition has been dealt with in psychology, physiology, and artificial intelligence — for instance, we can study the stimuli and responses associated with pain, but we find it harder to study the sensations associated with experiencing or recognizing pain (i.e. consciousness). Chalmers is specifically interested in the relationship between cognitive states and conscious states — that is, how and why stimuli of and responses to pain accompany the experience of pain (1996:26). How and why cognitive states (i.e. the actual neuro-physical states) are associated with consciousness is what is commonly referred to as the generation problem or the hard problem of consciousness (Seager 1999:216), which Chalmers sets out to illuminate.

To accomplish this, Chalmers proposes that there are two kinds of consciousness: psychological consciousness, which corresponds to the cognitive states discussed above, and phenomenal consciousness, which corresponds to the conscious states (Chalmers 1996:25-29).

Psychological consciousness consciousness consists of cognitive states and the capability to report on these states. Chalmers finds psychological consciousness completely explainable by the reductive functional paradigm to which cognitive science subscribes. It is simply that the paradigm that cognitive science uses is inadequate for explaining phenomenal consciousness, and it is phenomenal consciousness that Chalmers sets out to explain.

Phenomenal consciousness is sensation; it is the feeling-as-if quality that simply cannot be reduced to material correlates. Consciousness is a term for experience, a qualitative feeling held by the subject. A precise definition of consciousness, claims Chalmers, eludes the analyst of consciousness and as such it is more fruitful to describe it rather than define it. The reason that conscious experience cannot be described in a definitional way is that consciousness is intrinsic to the individual. The language we use to define consciousness is extrinsic and therefore a definition of consciousness using language would reduce consciousness to an extrinsic form. The result of course would not be a definition of consciousness but rather a definition of a reduced version of consciousness.

Chalmers' Notion of How Cognition and Consciousness Are Related

Chalmers clearly does not isolate cognition from consciousness. In fact, there is good reason to believe that they are connected. When we experience the color blue, for instance, there is an associated perception of the color blue, which is being seen directly. Thus, a corresponding cognitive state is always associated with the conscious experience of blue. In this way, conscious experiences are accompanied by cognitive states and as such consciousness implies that cognition in some form or another is also present. What this means is that we can use what Chalmers stipulates about consciousness to shed light on certain aspects of the nature of cognition, since consciousness implies cognition.

It does not follow necessarily that conscious experience results from cognitive states, but some if not most of the time it does follow. When one is looking attentively at a bird flying from tree to tree, there is a phenomenal sensation associated with this attentive cognitive state. In this situation it is clearly the case that when a cognitive state appeared so did a corresponding conscious experience emerge. But often we do not receive a conscious experience associated with an awareness of the phenomenon. For instance, when we recall something, it does not have the same phenomenal impact as something that is occurring in the present. Frequently there are sensations involved with certain memories, but they usually have weaker phenomenal effects than first-hand accounts. In other words for the most part, consciousness is an occurrent phenomenon, whereas cognition need not be occurrent. Chalmers, therefore, distinguishes two kinds of cognitive awareness: awareness that is associated with *occurrent* thought and awareness that is associated with *non-occurrent* thought.

What Chalmers then does is to reduce his definition of awareness to occurrent thoughts (to match with the thoughts associated with consciousness) and, in so doing, constructs his *principle of structural coherence* between cognition and consciousness (Chalmers 1996:218-225). The arrows of implication now flow in both directions between cognition and consciousness since they both constitute occurrent phenomena; this is to say that conscious experience implies cognitive awareness and cognitive awareness implies conscious experience under this reduced definition of cognitive awareness. There now exists a one-to-one correspondence between awareness and experience, such that where an awareness exists, an experience is entailed, and where there is an experience, an awareness is entailed.

The principle of structural coherence between cognition and consciousness simply states that the structure of cognition — when and how cognition arises in a dynamical system — can function as a model for the structure of consciousness, since there exists a one-to-one correspondence between awareness and experience. Chalmers does not claim to be able to determine the magnitude of experience from a corresponding magnitude of awareness from this principle, but the principle does guarantee conscious experience given cognitive awareness. It is therefore natural to suggest that consciousness is reliant on the functional organization of the brain, which produces cognition and consequently consciousness. "On this view, the chemical and indeed the quantum substrate of the brain is irrelevant to the production of consciousness. What counts is the brain's abstract causal organization, an organization that may be realized in many different physical substrates" (1996:247). The functional organization of the brain "...is best understood as the abstract pattern of causal interaction between various parts of a system, and perhaps between these parts and external inputs and outputs. A functional organization is determined by specifying (1) a number of abstract components, (2) for each component, a number of different states, and (3) a system of dependency relations, specifying how the state of each component depends on the previous states of all components and on inputs to the system, and how outputs from the system depend on previous component states" (1996:247).

Chalmers naturally assumes that functional organization is behind the generation of consciousness, since the functional organization is clearly what is behind the emergence of cognition. Since Chalmers deals with the subset of cognitive states responsible for occurrent thought, then it is clear to him that the associated functional organizations responsible for cognition (i.e. all cognitive states) are, in turn, initiating consciousness. Chalmers mentions a few of the "different physical substrates" in which cognition and hence consciousness can be realized — beer cans being just one (1996:249). This tapered form of *panpsychism* is not new as it has been advocated by John Tyndall and Thomas Huxley (Seager 1999:216-217). Block (1978) has even proposed that if enough people were fitted with a radio transmitters and receivers that conscious experience similar to that achieved by a human brain could be supported. In this manner, human interaction can produce the phenomena of cognition and, hence, memory formation, as well as consciousness that we usually attribute to the human brain.

Chalmers' analysis of consciousness manages to show that phenomenal consciousness is non-reductively explainable. (It was cognitive awareness that could be reduced to occurrent thought, not consciousness.) As such, Chalmers sets the foundation for a scientific theory of phenomenal consciousness, but he does so in a way that also sheds some light on his views of cognition. The first and most important thing that can be said of Chalmers' view of cognition (indirectly since his concern is with consciousness) is that cognition is dependent on the functional organization of a materially based dynamical system and that this system can manifest itself in any medium or substrate. In other words, it is the functional organization or systemic interaction of the components that causes cognition, not some innate material property of the components themselves. Finally, Chalmers sees cognitive states as being divided up into occurrent thought and non-occurrent thought, and he asserts that occurrent thought is irrevocably tied to consciousness. This may be his strategy for explaining consciousness — to divide cognitive awareness into occurrent and non-occurrent thought — but it nonetheless gives us an idea of how Chalmers conceives of cognition. He sees the subset of cognitive states known as occurrent thought as determining consciousness, and it is the structural coherence between cognitive states and conscious states that he concentrates on throughout the remainder of his book.

3.4.3 Clark and Chalmers and Active External Cognition

Clark and Chalmers' 1998 work makes a significant departure from Chalmers' 1996 work, which I have just discussed. Chalmers 1996 emphasized supra-individual cognition, whereas Clark and Chalmers 1998 emphasize extended cognition.

Clark and Chalmers (1998) explore the issue of the physical limits of cognition. They suggest that cognition is erroneously conceived of as an internal neuro-physiological phenomenon, since most people associate "the mind" or cognition as being a phenomenon of the brain only, restricted to within the skull of the individual. This *internalist* perspective is not telling the whole story, however, since it abstracts cognition from its context, which is the surrounding environment and the objects therein that we use to enhance cognition. In contrast to the internalist view, which as we have seen has its historical reasons for arising (see Section 2.2), the *externalist* perspective does not set boundaries on where cognition ends.

To explain their argument, Clark and Chalmers (1998) propose three hypothetical situations.[12]

1. In the first hypothetical situation, Clark and Chalmers (1998) have the reader envision an experiment in which a person is situated in front of a

[12]In their argument, Clark and Chalmers (1998) draw heavily from Kirsh and Maglio's (1994) observational studies of subjects playing the video game Tetris.

computer screen that depicts different geometric shapes and associated sockets, which the geometric shapes may or may not fit into. The subject is then asked which sockets the geometric shapes will fit into. The subject must of course conduct all of the mental acrobatics needed to accomplish this task within his or her brain.

2. In the second situation, the same experiment is conducted, but this time, by pressing a button, the subject is allowed to choose to rotate the shapes on the computer screen to see if they fit into the sockets being presented to the subject.[13]

3. In the third scenario, a neural mechanism is implanted within the subject's brain that allows the individual's brain to rotate the shapes in the way a computer does. Again it will be assumed that this implant decreases the time it takes to determine which shapes fit in the sockets.

Clark and Chalmers suggest that cognition is depicted in all three scenarios. Certainly, no internalist would deny that the first scenario does not depict cognition. Similarly, an internalist would be hard pressed to explain why the third situation could not be considered cognition. Finally, since the neural implant duplicates the computer's actions, the internalist would have to admit that the second situation is cognition as well.

All three situations can be regarded as *epistemic actions* (Kirsh and Maglio 1994). That is, they are all actions that help *to determine if* a shape fits into a socket. These actions contrast with *pragmatic actions*, which only rotate a shape to fit a socket for the sake of rotating a shape to fit a socket. In the epistemic case, the subject is *learning*, which is clearly a cognitive

[13]It will be assumed that this procedure decreases the time it takes to decide which shapes fit into the sockets.

process. In the pragmatic case, the job of fitting the shape into the socket need not entail learning, just task completion.

The second hypothetical situation is interesting since it is a case in which cognition crosses the boundary of the skull. The notion that cognition extends beyond the biological individual is called externalism. Clark and Chalmers (1998) do not advocate a *passive externalism* as does Putnam (1975), but instead advocate an *active externalism*, in which the subject and the external device that the subject is using are involved in the cognitive process. That is, it is not only a case in which the individual's mind is being represented in different media around him or her, but it is a case in which these media actually supply information that aids the individual in processing data. In other words, there is feedback from an external source (e.g. calculator, computer, notepad and pen). What develops is not a cognitive nexus centered within the individual's brain and an added-on device for aiding information processing, but an entirely different dynamical system with no precise center, where human and device are *coupled*. For example, this coupling or interaction has been demonstrated to comprise human visual systems in which features in the physical environment have been shown to enhance certain visual properties in the human brain (Ullman and Richards 1984).

Externalism does not stop with features in the environment or with mechanical devices such as notebooks and computers; it also includes other people. When we interact with people using language (i.e. discourse), we learn. Discourse thus constitutes an epistemic action and extends cognition to include all people that are involved in the discussion. Language, therefore, is critical for "extending" cognition and therefore can be seen to function as a factor in evolution, which relates to Donald's (1991) work. All three authors, Donald, Clark and Chalmers view the capacity for humans to employ external sources in the cognitive process as an adaptive advantage for *Homo sapiens*. For Donald, however, the externalism is focused on external storage, whereas Clark and Chalmers subscribe to a continuously ensuing cognitive process — a dynamical system that entails interacting subject and environment. All three authors see the evolution of human cognition as the developmental process in which humans employ more and more external sources in the cognitive process — i.e., cognition becomes more and more extended.

As a result of cognition being extended, it is a natural suggestion, according to Clark and Chalmers, that the "self" too is extended. For example, the identity of a person does not consist only of the person, but includes the computer he or she may be using as well. The self in this way is extended to include the objects we use on a daily basis and the friends that are always with us.

This notion of extended *self* has been described by Mageo (1995). Mageo claims that in Samoa, it is very difficult to understand why Samoans do the things they do unless some understanding of how Samoans perceive the self is acquired. Samoans see the self as including the entire family, and an injustice done to one person in the family is a disgrace to the entire family. In essence, one individual is represented by all of the family members.

Clark and Chalmers see cognition as potentially limitless and there is significant research to support their view (e.g. Port and van Gelder [1995], discussed in the next section). Not only should discourse and material objects be the focus of externalist cognitive studies, but so too should other actions besides discourse be examined as extended cognition. I will focus on actions and, in particular, interactions throughout this thesis.

3.4.4 Van Gelder and Port and Turvey and Carello on the Agent/ Environment Relationship

Port and van Gelder (1995) provide an extensive review of the dynamical systems approach to cognition in their edited book. I will only consider two papers from their book.

In van Gelder and Port's (1995) section, "It's About Time", van Gelder and Port provide the substantiation for why a dynamical systems view is critical to future studies in cognition. Their main line of defense is that dynamical systems models are not just a way of representing natural cognitive systems — systems with cognitive capabilities — natural cognitive systems *are* dynamical systems. They refer to this proposal as the "Dynamical Hypothesis", and though such a proposal can only be tested through time, one central observation supports the view that natural cognitive systems are in fact dynamical systems. Their observation is that natural cognitive systems are not cyclic and sequential, as the computational view entails; that is, one component does not represent something to another component, as discussed in van Gelder (1995) and in Section 3.2. Rather, all of the parts of cognitive systems are continuously changing in real time. The brain itself is an indication of this. Mental processing is the result of an organic mass of electrical and chemical interactions, all of which are governed by natural dynamic laws acting on the neural architecture of the brain through time.

Dynamical systems also describe the *whole* cognitive process better than any other means currently known. From an externalist perspective, cognition is not encapsulated within the brain of the individual; it subsumes the nervous system, body, and environment (van Gelder and Porter 1995:13). Cognition is the process of all three of these entities working together simultaneously, not sequentially, and it is therefore more accurately described as a dynamical system.

A good example of the kind of work that is advocated by the authors is empirical work demonstrating that people are attuned to dynamical systems, and that this attunement helps people to perceive and process information. One such example is the work of Turvey and Carello (1995), who provide empirical evidence supporting the view that perception is attunement to the features of a dynamical system. Their case study entails demonstrating that a dynamical system of a person wielding a hammer is a natural cognitive system.

In this work Turvey and Carello study human perception and action to see if these phenomena are keyed into the dynamical systems that form externalist sorts of cognitive systems. In so doing, their research not only provides empirical support for externalism (i.e. extended cognition), but their work also empirically supports the view that cognition is indeed a dynamical system, since the subjects being tested actually perceive the constraints of the dynamical system described by the parameters of the dynamical system's model.

Turvey and Carello's work on perception is two-fold:

1. The first purpose of the authors is to construct a model of the physiological dynamical system, which describes a human acting in his or her environment.

2. The second purpose is to determine whether the subject, through his or her actions only, is attuned to features of the dynamical system of the human-environment action. If the subject is attuned to the model of the dynamical system then this suggests that the dynamical system is not a figment of the experimenter's mind, but is *actually* part of the subject's mind.

(a) This second purpose is accomplished through first determining whether the subject perceives the environment through action correctly. That is, the subject's perceptions of the environment — the subject is blindfolded and must use actions to perceive the environment — are compared with the actual environment to determine if they are correlated.

(b) The second step is to determine if the subject is attuned to any of the parameters of the dynamical model and, if so, to determine what parameters of the dynamical model the subject is attuned to.

Turvey and Carello first begin their study by constructing a dynamical model of a human wielding an object around a fixed point in the wrist using the Euler's equations:

$$I_1\frac{d\omega_1}{dt} - \omega_2\omega_3(I_2 - I_3) = N_1 \tag{3.16}$$

$$I_2\frac{d\omega_2}{dt} - \omega_3\omega_1(I_3 - I_1) = N_2 \tag{3.17}$$

$$I_3\frac{d\omega_3}{dt} - \omega_1\omega_2(I_1 - I_2) = N_3, \tag{3.18}$$

where I_1, I_2, and I_3 are the moments of inertia in the 3-dimensional space centered at the fixed point in the wrist; N_1, N_2, and N_3 are torques around the associated axes anchored on the fixed point in the wrist; and ω_1, ω_2, and ω_3 are the angular velocities about the associated axes, the derivative of which represents the angular accelerations.

Turvey and Carello then have their subjects wield objects of various, weights, lengths, and shapes, while blindfolded. Through wielding the objects the subjects are then asked to estimate the lengths of the objects wielded.

When these estimates were compared with the actual lengths of the objects, the subjects' estimates of the lengths were close enough to the actual lengths of the objects to suggest that the objects' lengths were perceived through wielding the objects. This showed to the experimenters that a dynamical system, described by the equations above, subsumed both wielder and object, and that it was this dynamical system to which the wielder was attuned.

The experimenters then went through the process of searching for the features of the dynamical system, manifested in the parameters of the dynamical model, that the subjects were keyed into. Through regression, Turvey and Carello were able to determine which parameters correlated with the perceptions of the subjects, hence homing in on the parameters of the dynamical system to which the subjects were attuned.

Turvey and Carello's work provides a concrete example of how extended cognition in the form of a dynamical system can be studied and I will draw on their research periodically throughout this thesis.

3.5 Defending Strong AI from a Dynamical Systems Perspective

Defending (strong) AI is important for my research because AI is the hypothesis that cognition can be *duplicated* in any substrate. A defense of AI, therefore, constitutes a defense for substrate independent cognition which in turn is necessary to support the notion of supra-individual cognition, as well as extended cognition.

In this section, I take up two more objections against AI, which were briefly mentioned in Section 2.3.5, and defend them. I chose to discuss these objections at the end of this chapter because the notions of extended and supra-individual cognition — which are based on the idea that cognition is of a (strong) *functional* nature — are relevant for defending AI. For example, the defense of the first objection (below) requires an understanding of the notion of extended cognition (i.e. from the individual into the environment), and the second objection (below) requires an understanding of the notion of cognition as a dynamical system.

The Third Objection to AI

A major objection to AI is that computers cannot possibly exhibit human-grade cognition since humans interact with the world around them and computers do not. In other words, much of human cognition comprises things that we have learned through interacting with the environment or with other people. Computers do not interact with other computers and the environment in the same way as humans do; therefore, computers will not have the same "kind" of cognition that humans have. In other words, culture and society have a definite impact on our mental content that computers cannot match.

An example supporting this objection is the ability to compare and contrast the thinking of Chinese and American individuals (Hergenhahn 1992:549). It is argued by opponents of AI that Chinese and Americans think differently even though they have the same neural functional organization. Clearly, something from outside of the brain is happening to differentiate the thought processes of Chinese and Americans. Computers, on the other hand, do not form societies and therefore do not exhibit these characteristics.

This objection, however, does not adequately make its case that an individual's "thinking" is not the same for Americans and Chinese. If abstracted from the effects of society, individuals do seem to think alike. An individual born in China to Chinese parents, but raised in America from an early age thinks much the same as any other American individual; the converse is true for an individual born in America to American parents, but raised in China from an early age. In other words, the common denominator for functioning in the world is present in every individual from the time of birth. Only after birth does society begin to affect an individual thinking.

Therefore, while I disagree that this objection shows that individuals are different from one another despite having the same neural architecture, I agree with the fact that society does have an effect on "thinking". I would also add that the reason that we have computers that do not have this added interactive dimension is that we do not fully understand how society affects humans. Consequently, if we do not understand how society affects humans then we cannot possibly be expected to instill social effects into a computer.

We cannot build a computer that can supplement its thought processes with the thought processes of other computers or the environment since we do not understand how the same phenomenon occurs in humans. However, progress is being made. Currently, research is being conducted on just this topic with computer simulated experiments (Kennedy 1998) (see Section 2.4.2) and with robots (Maris and te Boekhorst 1996) (see 2.4.3). Maris and te Boekhorst (1996) have found that AI does in fact interact with the environment and other AI. This interactive phenomenon has been a topic of AI research for over a decade and it gives credence to the notion that there is supra-individual cognition working together with individual cognition.

Whereas Kennedy's (1998) and Maris and te Boekhorst's (1996) research have focused on the social environment, other research is being conducted which is focused on the physical environment. Turvey and Carello's (1995) research has concentrated on determining the effects of aspects of the physical environment on cognition and what they have found is that cognition manifests itself as a dynamical system subsuming nervous system, body, and environment (see Section 3.4.4). The implication of this is that the human body is important for cognition, since it forms an integral component in the dynamical system which facilitates perception. Take the body out or change its form and the entire dynamical system subsuming nervous system, body, and environment would change, thereby changing how things are perceived. If preservation of the dynamical system responsible for cognition is important in forming human-grade cognition then it would seem that the body would similarly need to be artificially reproduced in order for the AI to attain the same level of cognition of humans.[14]

This research supports the view that AI units can and sometimes do unpredictable things (especially when incorporating the effects of the environment on cognition), which was the second objection raised in Section 2.3.5.

The Fourth Objection to AI

Another objection against artificial intelligence is quite simply that a computer is not a brain. This objection was raised briefly in Section 2.3.5. The

[14]I should point out, though, that this does not mean that human cognition is superior to cognition that might manifest itself in a dynamical system with a different body type. It only means that to duplicate human-grade cognition it would probably be necessary to construct for the AI a body of human proportions and capabilities.

objection against artificial intelligence follows that just because artificial intelligence imitates cognitive processes in the brain does not necessarily imply that they reflect human-grade cognition.

Proponents of strong AI would defend themselves by stating that if the basis for human intelligence and artificial intelligence is functionally equivalent, then for all intents and purposes they are the same (Hergenhahn 1992:549).

However, opponents to AI would argue that functionality is not enough to claim that two things are the same, for if this were true, then many phenomena in the natural world could be regarded erroneously as cognitive processes. An example of someone who holds this view is Searle (1980).

Searle (1980) demonstrates that a computer is not a brain — that is, a brain does not only manipulate symbols according to rules in the way a computer does — by proposing a thought experiment. In this thought experiment, called the "Chinese Room" rebuttal, a man who does not know Chinese sits in a room where baskets of questions written in Chinese characters are slipped in and baskets of answers in Chinese characters are slipped out. The man in the box, even though he does not understand Chinese, has a rule book that tells the man what characters to put together in order to respond to a question. That is, the rule book tells the man how to manipulate symbols. The man in the box, following the rules, then writes an answer on a piece of paper and slips it out of the room. The problem, however, is that the person in the room, who metaphorically represents the computer, does not actually understand the characters. He is simply passively following rules in the rule book, where the rule book metaphorically represents a computer program.

Searle's (1980) main point is that outputting correct answers to questions by manipulating symbols according to rules does not mean that the computer understands Chinese. This is because to understand Chinese is to demonstrate some *executive control over* symbolic manipulation. Thus, demonstrating symbolic manipulation is not a strong enough condition for demonstrating that the computer *has control over* the way symbols are manipulated; that is, the mere fact that the computer can manipulate symbols does not imply understanding and, hence, human-grade cognition.

What Searle has to say about control over symbolic manipulation, or what he refers to as consciousness (Searle 1990:29), does impact cognition in a fundamental way and we must therefore address this issue. This is because Searle's main point can be taken to be that just because something looks like cognition from the outside does not necessarily mean it is cognition. Being a weak functionalist is not enough for demonstrating cognition; rather, it is also the processes involved in generating cognition which are integral.

I agree with Searle on this point; however, in light of the fact that research has been tending to favor conceiving cognition as a dynamical system in which executive control (i.e. "the will") is a property that emerges from dynamical systems, and is distributed in systems that form networks (see Sections 2.2.2 and 3.2.2), Searle's objection does not have the same force as it did when Searle was arguing against the computational view of cognition. This is because Searle was really arguing against computationalists' reliance on weak functionalism as support for computational cognition. Now that cognition is generally regarded to be a dynamical system, AI advocates use strong functionalism to support a dynamical view of cognition, which renders Searle's objection ineffective. (Refer to Section 3.2.3, where I distinguish weak functionalism and strong functionalism.)

To demonstrate that Searle's argument no longer carries weight against AI, let us consider another of Searle's examples. Searle (1990:31) states that a water molecule cannot be duplicated simply by building a model of a water molecule using ping-pong balls any more than cognition can be duplicated by a Chinese room (or a man in a Chinese room).

However, one argument as to why water cannot be duplicated using ping-pong balls is that three ping-pong balls glued together do not constitute the same molecular system as do two atoms of hydrogen and one of oxygen. Water is a material phenomenon, not a strong functional phenomenon. Being a material phenomenon and therefore dependent on different types of material, there will be no molecular forces acting between ping-pong balls as there are between the hydrogen and oxygen atoms since ping-pong balls constitute a different material type. Model and reality in this case are not the same in all respects. Therefore, Searle is correct about water and the ping-pong ball model of water being different, but this is because his analogy does not consider a functional phenomenon but rather a material phenomenon, which cognition is not.

What Searle fails to realize is that cognition, or more specifically the capacity to process information, is a holistic phenomenon that emerges from a system rather than from the individual parts that make up the system (e.g. water). Strong functional phenomena, such as cognition, do not require that the material constituents (e.g. biological neurons and artificial neurons) be the same between two dynamical systems generating cognition, only that the dynamical systems *themselves* that produce cognition are the same. Information processing, because it is a functional phenomenon, transcends different types of material media. This has been shown in AI studies in which we can duplicate information processing of biological neural structures in artificial neural structures of completely different physical substrates — one of organic tissue, the other of silicon (Churchland and Sejnowski 1992:416-418).

It was the dynamical system comprising the biological neural network that allowed an artificial neural network to be constructed (Churchland and Sejnowski 1992:416-418). The biological neural dynamical system was studied and mathematically described. Then the understanding of how the biological neural dynamical system worked was transferred to an artificial substrate. Once this was accomplished, it was possible to duplicate the biological neural dynamical system in silicon circuitry. Lazzaro and Mead (1989) and Mead (1989) created a synthetic retina and cochlea (part of the auditory cortex) based on what was known of the mathematical mechanics behind biological cognition. The substrate changed, but the fundamental mathematical principles describing cognition remained unchanged. This has been tested many times and will therefore be taken to be an irrefutable point throughout the remainder of this thesis.

3.5.1 An Evaluation of the Cognitive Research

The picture that has been painted of cognition is that it is a substrate independent phenomenon. With regards to notion of *extended cognition* discussed in Sections 2.4.4, 3.4.3, and 3.4.4, it might appear to the reader that by including the individual in the definition of extended cognition that cognition is no longer substrate independent. This reasoning, however, would be incorrect. Cognition is still substrate independent; it just requires that it subsume another information processor that *perceives* it. In practice this ulterior information processor that is subsumed by cognition is a human individual, but in theory it may be any kind of information processor if we accept the arguments that have been made for AI.

Although the authors, whose work was discussed in Sections 2.4.4, 3.4.3, and 3.4.4, do not explicitly say so, the "individual" can theoretically constitute anything that is capable of *perception.* This is because dynamicists like the computationalists are functionalists and being functionalists suggests that the authors would not be opposed to the notion that humans, animals, and even AI could conceivably function as the "individual" in extended cognition. The fact that humans are utilized as the subjects of extended cognition studies (e.g. Clark and Chalmers 1998; Turvey and Carello 1995) has to do more with pragmatic reasons rather than reasons which owe to the uniqueness of humans. A clear example of an author that is a major proponent of the fact that cognition is substrate independent yet utilizes humans in his case studies is Chalmers. Chalmers' (1996) views of cognition are *panpsychic* in the sense that he proposes that cognition can arise potentially anywhere in nature. However Chalmers' case studies predominantly entail the use of humans as his frame of reference (e.g. Clark and Chalmers 1998).

This discussion leads me to propose two essential ingredients in cognition: *information processing* and *perception.* The notion that cognition is information processing began in the 1950s with Turing (1950) and it still remains the predominant framework to which cognitive scientists, as computationalists and dynamicists, adhere. What perception adds to information processing is a way for the subject to receive information and hence interact with the subject's environment. It also provides the observer or analyst with a way to realize someone else's or something's cognitive capabilities.

Beliefs and memories are the products of information processing (van Dijk 1998) and what perception adds to this is a way for the subject to receive the information needed to formulate these beliefs and form these memories. Perception is also important for the observer or analyst who studies cognition. This is because perception is the proof that an information processor being analyzed is connected with the rest of the world and has the potential to interact with it, feed off it, and change it. For example, without perception there is no evidence that the information processor in question can interact with the world like a human might. In short, the notion of perception is important, because it not only introduces the information processor to the world, but it provides cognitive scientists with a frame of reference with which to study cognition.

3.6 Conclusion: The Status of Systems

In the research discussed above cognition is regarded to be a dynamical system rather than computation, and this means that models of dynamical systems are better than computational models at describing cognition in general. This work supports an externalist view of cognition which encompasses both individual and environment in a unified or *coupled*, interactive system. It also supports a supra-individual view of cognition.

The term "computational," as discussed above, means symbolic. It refers to the idea that cognition is algorithmic, consisting of a sequence of procedures that are engaged as soon as preceding procedures complete their tasks. The term comes from the manner in which computers operate, in a sequential, non-systemic manner.

In this chapter, it has been argued that cognition constitutes a dynamical system. The implication of this statement is far-reaching; if cognition constitutes a dynamical system, then dynamical systems models used to describe natural cognitive systems are not just *tools*; cognition is actually embodied in the dynamical systems models used to describe the cognitive phenomenon. This rather compelling line of thought is interesting for the way that it contrasts with the way systems have been treated in the social sciences and especially in archaeology.

In recent years, systems have been relegated the status of simple tools used for describing behavioral causes and effects in the archaeological record (Shanks and Tilley 1992:118; James McGlade, personal communication 2000). The reason for the tendency to use systems in this way is simple: we can only systemically model what we can see. Hence, systems are primarily used for conceptualizing bounded, interacting phenomena such as subsistence practices, exchange, and other social phenomena that are manifested materially. In fact, the model I develop in this thesis is no exception because I systemically model exchange in Chapter 6. However, this does not mean that systemic modeling *only* illuminates the materially manifested behavior that is being studied (e.g. exchange, subsistence). Dynamical systems that are modeled can constitute natural cognitive systems — like those described in Port and van Gelder (1995) (e.g. Turvey and Carello [1995]) — that the past people being modeled were perceiving. This means that the systems which archaeologists as outsiders are conceptualizing are not necessarily *etic* tools that are being forced on the ancient peoples being modeled; the systems that are being conceptualized may be actual windows into past people's minds. I pursue this line of thought in Chapters 7 and 8.

Despite the widespread *formal* use of systems theory in archaeological research (Clarke 1978; Renfrew and Cooke 1979; Renfrew, Rowlands, and Segraves 1982; Lake 1995, 2001; Abramiuk 1999b), the full potential that systems theory has in store for archaeology, particularly for cognitive archaeology (Renfrew and Zubrow 1994; Renfrew and Scarre 1998), has not been exhausted. Archaeologists using systems may have examined how cognition *affects* subsistence and exchange (e.g. Flannery and Marcus 1976), but not how subsistence and trade *effect* cognition. Research into this latter issue would have a great deal of application for archaeologists, and I propose that dynamical systems theory plays an important role in such research.

From the late 1970s onward, many archaeologists concerned with cognition turned their backs on systems or relegated them to the status of tools, believing systems held no promise for providing insight into the "thoughts" of past peoples (Johnson 1999:90). Archaeologists were swayed in the direction of symbolism as a means of illuminating cognition in the archaeological record (Hodder 1982; Shanks and Tilley 1987). A symbolic approach, however, is a computational way of conceptualizing cognition. The symbolic view, which has been the cognitive post-processual way of analyzing material culture (Hodder 1982), perceives cognition as analogical chains, which is precisely what is involved in computation.

The computational approach still remains a fruitful way of explaining many cognitive phenomena, and it provides a useful paradigmatic lens with which to view cognition. However, this likely has to do with the fact that it is easier to conceptualize a sequence of events rather than a simultaneity of events operating as a dynamical system. The problem with any symbolic approach to cognition is that it abstracts the phenomenon studied from its original context in real time, thereby detaching the phenomenon from the process by which it was created. Dynamical systems provide a more conceptually pure and accurate depiction of cognition than computation does.

Part II

The Economic Approach and the Model of Exchange Along the Bladen Branch

Chapter 4

The Basis for an Economic Approach to Classic Maya Exchange

In the last chapter, and indeed throughout the first part of the thesis, I focused on different conceptions of cognition. In this chapter, I will temporarily turn away from cognition to concentrate on theoretical issues in economic archaeology which are pertinent to my investigation of Classic Maya ground stone exchange in the Bladen region of the Maya Mountains of southern Belize. The reason for investigating a case study of exchange in a thesis dedicated to cognition is that the process of exchange can be shown to exhibit features which constitute it as supra-individual cognition.

Harkening back to the title of this thesis, it was suggested that an "economic approach" to Classic Maya ground stone exchange would be discussed and from this would emerge certain "cognitive implications". I did not broach the topic of economics because I believed that providing a background in cognition was essential before I began illustrating how cognition could emerge from economic exchange. It is now appropriate that the economic approach I take to study Classic Maya exchange be discussed in detail.

In Chapter 6, I will construct a model of Classic Maya ground stone exchange in the Bladen region. However, in order to construct a model of exchange it is necessary to discuss the economic premises on which I base my model. These premises form the economic approach I utilize to model Classic Maya ground stone exchange in the next chapter. The purpose of this chapter is to situate the economic approach I utilize in its theoretical context.

4.1 Economic Anthropology/Archaeology

Economic theory in anthropology and archaeology has passed through several theoretical turning points. In this section, I briefly discuss these theoretical perspectives and how they relate to my outlook on economic theory and how they can be used for modeling exchange in the Maya Mountains during the Late and Terminal Classic period.

Two of the most important economic theories are formalism and substantivism (Polanyi 1957:243). Formalism is the notion that modern "western" economic theories can be used to understand the economic aspects of ancient or "non-western" societies. Substantivism is the notion that the premises upon which modern western societies are based are not present in ancient or "non-western" societies; therefore, modern economic models with their assumptions are inapplicable to ancient society or indeed to any non-western society.

It is important to remember that, as with many theories in anthropology, the theory that is advocated is dependent upon what kind of phenomenon is being studied as well as the scale of the investigator's analysis (i.e. individuals versus large groups of people). Another important thing to remember is that although formalism and substantivism are theoretical views that are often pitted against each other, they can nevertheless be regarded as occupying opposite ends of the same economic theoretical continuum. I will discuss this continuum next, beginning with the strongest varieties of the substantive and formal approaches at the ends of this continuum.

4.1.1 Substantive Economics

Substantivism was introduced in the 1950s and 60s by Karl Polanyi (Polanyi 1957). Polanyi envisioned three kinds of economies, two of which were substantive and one of which was formal. Formal economy, also known as western industrial capitalism, is subject to a completely different analysis and will be discussed in its own section. Substantive economies, on the other hand, consist of *reciprocity*, a form of exchange that is prevalent in band and tribal society, and *redistribution*, a form of exchange which is common in chiefdom society (Sahlins 1968:93-95). The notion of substantivism is best defined in Polanyi's own words:

> "The substantive meaning of economic derives from man's dependence for his living upon nature and his fellows. It refers to the interchange with his natural and social environment, in so far as this results in supplying him with the means of material want satisfaction" (Polanyi 1957:243).

In this excerpt, Polanyi stresses that economics in the substantive view is first and foremost *social*. "Man" and what he has in his material possession is dependent on other people and on his environment. In other words, a characteristic of the substantive approach is that the individual plays little or no role in the overall economic phenomenon (Hopkins 1957:294-295). An individual's will, wants, and desires are subsidiary to the encompassing social and environmental context subsuming the individual. This does not necessarily mean that the substantivist denies the existence of individual will, but rather that individual will is not the focus of analysis for the substantivist, who instead is more concerned with grander scaled phenomena involving communities of individuals.

A second point that Polanyi emphasizes is that there is an "interchange" between people and their environment. Polanyi envisions relationships between people and between people and their environment as being responsible for what each member of the society actually has in his or her material possession. As a result, any profit-making is a byproduct of what people really do, which is to contribute to society and maintain the social system.[1] The notion of a system in Polanyi's substantive economic approach is therefore essential to understanding how particular economies evolve. It can be inferred from Polanyi that because the economic situation in which people find themselves is directly linked to their social and environmental state, an understanding of an individual's economic state is explicable through the states of the social or environmental system being considered. As I discussed in Section 3.4.2 with regards to the work of Chalmers (1996), this explanation is referred to as a *reductive functional explanation* and is one of the most powerful means

[1]Note, the way that *system* is used here is not unlike the way *dynamical system* is defined in the *Glossary*. As such, the terms "system" and "dynamical system" will be used, for all intents and purposes, synonymously in this chapter. What is implicit in the way substantivists and indeed in the way macroeconomists use the term "system" is that the "system" is generally regarded to be stable, which is not assumed in dynamical systems theory.

of explanation and for this reason is popular in the sciences.[2]

In the substantivist view, people do things in order to maintain a economic system. The system exists as an *a priori* assumption set out by the substantive economic analyst and the analyst proceeds as if the system, or more accurately the *constraints* that give structure to the system, exist as tangible factors that are perceptible by the people in the system. This is interesting and important because the substantivists endow the system with an established existence in a manner analogous to the way that dynamical systems advocates treat cognition (recall the discussion of Turvey and Carello [1995] in Section 3.4.4). This is a critical point because the cognitive/dynamical systems school of thought, which van Gelder and Porter and Turvey and Carello (1995) advocate, is in a way supporting empirically what the substantivists have been assuming — which is that economic systems are not just "mind-models" for the analyst (i.e. etic), but may actually be "mind-models" for the people that the analyst is studying (i.e. emic).[3] In other words, some substantive models may in fact describe cognitive systems for the people involved in the economic system that the analyst is modeling. With more research on cognitive/dynamical systems, the assertion that ancient or non-western peoples maintain a "system", may be supported with empirical evidence.

[2]Substantive economics is usually associated with macroeconomic theory, which contrasts with the traditional economic theory laid out in Adam Smith's *Wealth of Nations*, first published in 1776. The reason for the contrast is that macroeconomic theory deals with systems of large groups of people and their total economic output (Schneider 1974:43), such as an entire nation's Gross Domestic Product (GPD). They do not deal with an individual's motives and incentives, which comprises much of the subject matter for microeconomists.

[3]The term "mind-model" is taken from Clarke (1978:45).

However even with the empirical evidence, substantivism's reliance on an unproven hypothesized system cannot altogether be regarded as an assertion. It is substantiated in at least one respect, and that is with regard to the system's states. The system's states, whether they are in terms of the number of goats, people, or the amount of hard currency, are real entities that exist for the people being studied by the substantive economist as much as they are external indices for the substantive analyst. As such, the people being studied probably are aware of the external indices that are used by the analyst. In other words, it can be inferred that people in general are attuned to external indices reflecting the states in the economic systems that substantivists model (Hopkins 1957:294-295), though it is unclear whether or not the people are attuned to the constraints that structure the system.[4] The *states* of the system, if the reader recalls Section 3.2.1, are the variable features of the dynamical system, whereas the *constraints* of the system are those features of the dynamical system that remain constant.

The assumption that people work in order to maintain a system suggests that Polanyi also assumed the system to be a *stable* one in which people worked together in order to effect an equilibrium. However, as we have seen in Chapter 3, there are unstable systems as well as stable systems and, as such, it should not necessarily be assumed that a system is automatically stable. This is because the analyst usually does not know beforehand whether the system is going to be stable or unstable until after the model of the system is constructed and rigorously examined through mathematical analysis.

[4]Recall that Turvey and Carello's (1995) work showed that people were attuned to the constraints of the dynamical system described by the parameters that structured the system.

4.1.2 Formal Economics

Polanyi contrasts the substantivist approach to the formalist approach in the following way:

> "The formal meaning of economic derives from the logical character of the means-end relationship, as apparent in such words as 'economical' or 'economizing'. It refers to a definite situation of choice, namely, that between the different uses of means induced by an insufficiency of those means. If we call the rules governing choice of means the logic of rational action, then we may denote this variant of logic, with an improvised term , as formal economics.
>
> The two root meanings of 'economic,' the substantive and the formal, have nothing in common. The latter derives from logic, the former from fact. The formal meaning implies a set of rules referring to choice between alternative uses of insufficient means. The substantive meaning implies neither choice nor insufficiency of means" (Polanyi 1957:243).

Formalism is mostly concerned with how an individual acquires or purchases an item, how an individual chooses between one item and another item. In order to analyze people's choices in this way, however, the formalist must generalize about the nature of the individual. Individuals are said only to be concerned with getting the best quality for the least cost and as such they are often regarded as completely rational economic beings. In capitalist economy, people are regarded as selfish and self-serving. This contrasts sharply with view that substantivists take, which is that individuals serve the whole.

To the formalist, the individual is "real" and society is "imaginary". But *is* the manner in which the individual is constructed "real"? It seems that formalists are doing the exact same thing with regards to the individual as the substantivists are doing with society. On one hand, the formalist is correct to claim to study a "real" thing; an individual can be seen and felt. On the other hand, it seems as if the individual being considered is imaginary, since the formalist is really studying the "rationality" of the individual rather than a "flesh and blood" individual.

Formalism is mostly concerned with the logic of the economic argument, rather than with whether or not the precepts substantiating the formalist argument are correct (e.g. Knight 1941).[5] In other words, the formalist does not usually conduct a statistical survey of how people actually choose to do things. They are, for the most part, unconcerned with the psychology of the individuals or the social behavior of the groups of people that they are studying. Rather, they are concerned with the logic of the argument that follows from the assumptions made about the rationality of individuals. Formalists are concerned with the logic of the argument and the conclusions that the assumptions bring, not the assumptions themselves. This would be sacrilege for the substantivist who is mostly concerned about the assumptions behind the chain of logic. It is for this reason that formalism is regarded as a theory building approach whereas substantivism is not.

[5]Schneider (1974:26) notes that Lévi-Strauss's (1963) approach to anthropology is analogous to the formalist approach to economics. It is an approach which begins with certain premises and builds up logically from the premises. In so doing, the formalist approach sometimes encountering unexpected results, which is essentially how theory is formed.

Theory Building Through Deduction in Formalism

The notion of theory building is essential to this thesis, since the overall enterprise of this thesis is to take the first steps toward "building theory" regarding our understanding of human cognition. Building theory is also what sets formalism apart from substantivism, a distinction which is integral in understanding where my economic approach is situated theoretically. Therefore, an understanding of what constitutes theory building in economics and indeed in other fields (e.g. cognitive sciences) is necessary. To explain what is meant by "theory building", I turn to Schneider's (1974:22-30) discussion of the debate between Herskovits and Knight, published by Herskovits (1952:508-531).

Herskovits (1940) believed that classical economic theory was inapplicable almost everywhere outside of modern western society, since it conceives of an individual who is economic in all respects. Knight did not deny that classical economic theory had this conception of the individual; however, in defense of classical economics, Knight stated that the reason that the notion of the "economic individual" is used is that formal classical economic theory is *deductive* whereas Herskovits's anthropological approach is *inductive.*

Knight explained that the formal deductive approach was based on so-called "universal" characteristics of individuals, whereas the inductive approach (soon to be substantivist approach) was based on ethnographic data. Knight claimed that the problem with the substantive approach is that it relies too heavily on getting the assumptive facts straight and not as heavily on building theory about humankind. In this sense, Knight's formal deductive approach generalizes about human nature but it makes up for this generalization by making significant steps in understanding the universal aspects of human economic behavior.

All that is required of the formalist approach, according to Knight, is a common-sense knowledge of the premises since the rest of the approach entails formulating a sequence of logical if-then statements, which have the purpose of shedding light on some aspect of human nature above and beyond the initial assumptions that the formal analyst started off with. This is what the formal deductive approach entails and what theory building is all about. Substantivism does not have this capacity because it is involved with the particularities of the premises and thus does not see the larger picture of the universal aspects of human economic behavior. In this sense, the formal approach could be regarded as one that generates a coarse-grained (general) picture depicting a large scope. In contrast, the substantive approach could be regarded as an approach that generates a fine-grained (particularistic) picture depicting a very small scope.

Though Herskovits and possibly Knight would disagree, ultimately both are valid approaches that depend on the analyst's objective. If the objective of the analysis is to provide depth and theory, then it would surely be in the interest of the analyst to utilize the formal approach. If on the other hand the analyst is more concerned with detail and making specific observations, then it would probably be in the interest of the analyst to adopt a substantivist approach. Because the formal approach covers a broader area of study, the analyst is usually less *discriminatory* than a substantivist would be. That is, because the substantive approach is particularistic it requires the analyst to discriminate one set of data from another in order to probe the particular aspects of phenomenon the analyst is studying. In this sense, both formal and substantive approaches are important explanatory tools; it is just that the formal approach can be regarded as a tool for *comparing* data, and the substantivist approach is a tool for *contrasting* data.

In short, Knight concedes Herskovits's point that more attention should be placed on the particularities of the assumptions the formalist begins with, but that is as far as he goes. Knight insists that advocating false principles is shoddier than advocating false facts, maintaining that economics is a theoretical not a descriptive science (Schneider 1974:23). Schneider (1974:23) illustrates Knight's defense with an example. Schneider contends that the formal economic approach is analogous to one in which a theoretical physicist takes in constructing a general theory of matter. In order to build such a theory, a theoretical physicist might need to introduce imaginary substances or worlds. Such theorizing, according to Schneider, is a useful exercise, since it might illuminate areas of physics that are currently unobservable, yet are essential for proposing ways of understanding the manner in which our universe operates (like hypothesized particles, such as *tachyons*, in subatomic physics).

4.1.3 Shades of Formalism

As I mentioned in the beginning, substantive and formal economic approaches occupy opposite ends of a continuum, and there are several researchers (e.g. Nash 1961; Malinowski 1984; Firth 1964; Cook 1966; Goodfellow 1939; LeClair 1962; Barth 1967; Belshaw 1968; Salisbury 1969) who incorporate aspects of both approaches in their views. These researchers, Schneider (1974) recognizes, can be regarded as formalists who adhere to certain aspects which are substantive in nature. As a result, these formalist views may have more differences between them than they have differences with substantive economics. These different formalist views comprise the formalist social anthropological view, the materialist economic anthropological view, and the social exchange view (Schneider 1974:9-21).

Formal Social Anthropology

Formal social anthropology, which has been espoused by Nash (1961), Malinowski (1984), and Firth (1964), is stringently adherent to the view that the social dominates economics. This formalist school is closest to the substantivist end of the continuum, and this is especially apparent in the ethnographic writings of Malinowski. According to Malinowski (1984), exchange among the Trobrianders, specifically the Kula exchange phenomenon, escapes a purely formalist explanation.

The Kula exchange system is system of exchange that encompasses a group of several islands and entails the exchange of necklaces for bracelets and bracelets for necklaces. The bracelets are traded in one direction while the necklaces are traded in another. The resulting phenomenon constitutes two movements — bracelets on one hand and necklaces on the other — in opposite directions. Since the islanders frown upon any Kula participant hoarding items, it seemed to Malinowski (1984) that no purely formalist model — emphasizing a self-serving individual — could adequately explain Kula exchange. This is because for Malinowski, the Kula participants did not appear to be exchanging their goods to make a profit.

It can be argued, however, that some necklaces or bracelets do come with stories of important people that had owned the items in the past. Thus, owning one of these items that someone important had owned gives the temporary owner something to boast about among the temporary owner's peers. But why, then, do the owners give up their trophies after a certain length of time?

To an economic anthropologist this could mean one of several things. One is that prestige and the stories that an owner gains from the items have an expiration date. That is, the owner eventually becomes bored with the Kula item and is more than willing to give up his trophy when the time comes. The second is that there are many Kula items with interesting stories and therefore it is not difficult to give up an item in possession even if it is a significant trophy. The third is that selflessness is a virtue that is highly respected in Trobriander society and it is this selflessness that could be the reward for participating in the Kula exchange system. In this latter scenario, being selfless is not so altruistic after all, but rather profit-seeking. The last possibility is that the Kula exchange system is a means by which people come together to socialize, in which case the act of exchange could be interpreted as one which is directed at maintaining social bonds by having stories to tell. It is this latter interpretation that Malinowski advocated, and as such he remained a staunch advocate of the fact that Kula exchange served a specific social function.

Other social anthropologists are considerably more formalist than Malinowski. They propose that exchange and other economic phenomena can be subject to more formal scrutiny because self-serving incentives for economic behavior can be found in nearly all if not all cultures. It is this key element that separates these authors from the substantivists. Their outlook, however, is unique in that they do not regard economics as a way of studying human behavior at all. Rather, they see economics as a *type* of behavior. In other words, economic behavior is just one kind of social behavior. The social in this scenario plays a central role in that it is regarded as determining the economic behavior of people. In a way, the formal social anthropological view can be considered to be a social deterministic theory (in contrast to the economic determinism of Marx). To formal social anthropologists, economic behavior and social behavior are distinct phenomena, the former of which is subordinate to the latter. If conceived of in a systemic paradigm, society constitutes the system and economics forms a subsystem.

Since society dictates or determines economic behavior, it should stand to reason that even modern western society is designed in such a way as to enable the fostering of selfish profit-seeking individuals (Schneider 1974:13). In fact, that is exactly what a formal social anthropologist would concede. Since society determines the economic behavior of individuals, it is logical to suppose that capitalism is not a parasite attached to the belly of modern western society; rather, capitalism is more like an appendage that has evolved naturally as a consequence of the way modern western society is structured. Each society therefore breeds its own unique individuals with their own way of being "economically minded".

Materialist Economic Anthropology

According to Schneider (1974:14-17), the materialist economic anthropologists (Cook 1966; Goodfellow 1939; LeClair 1962) advocate a view that most closely resembles a classical economic view of society. Most of the anthropological advocates of this view have a strong training in economics. They believe that classical economic theory can be applied cross-culturally and, undoubtedly, cross-temporally. This mode of thought is truer to the formalist attitude on economic behavior than the social anthropological mode of thought.

Materialist economic anthropologists assert that economic behavior is distinct from social behavior. Unlike the social anthropologists, the materialists propose that an analyst can actually approach different societies from a classical economic standpoint, as long as certain modifications are made that are specific to the society being modeled. The materialists, in other words, are not insensitive to the differences between societies; nor are they ignorant of the fact that some aspects of societies are difficult to explain through classical economic theory. These aspects are namely the nonmaterial aspects of society — aspects that are difficult to measure.

Although the materialists accede that it is difficult to formally model nonmaterial phenomena, this by no means implies that it is impossible to formally model nonmaterial phenomena. The formal modeling of nonmaterial phenomena, however, entails that certain modifications be made in the manner in which classical economic theory is applied in these instances. And rather than focus on the modeling of nonmaterial phenomena and the associated changes that would accompany such modeling, the materialists prefer to focus on the material aspects of society because these aspects can be easily quantified. Indeed services can be quantified and subjected to economic scrutiny as long as there is an observable characteristic associated with the entity being modeled.

Though materialists claim that nonmaterial aspects of society can be subjected to economic analysis, few materialists, if any, actually succeed at modeling these nonmaterial aspects. The materialist methodology is similar to the classic sociological methodology that Durkheim (1933:64) espoused many decades ago. This consisted of his utilization of an *external index* to show that something is happening within society. According to this methodology, proper sociological practice requires that:

1. The analyst focus on a phenomenon in society that the analyst wants to explore.

2. The analyst choose a physical or material feature that best *reflects* the social phenomenon.

3. The analyst study the dynamics of the external index under the as-

sumption that the social phenomenon is manifested in the external index.

In this way, a study of the external index functions as a window for viewing the inner workings of society. Durkheim (1952), for example, used this methodology in *Suicide.* The phenomenon that Durkheim was interested in illuminating was the notion of suicide in society, and one of the external indices that Durkheim used to support his theory of suicide is the number of cases of deaths by one's own hand (1952). Similar to this, the materialist economic anthropologist studies the social phenomenon that he or she is interested in studying through some number of objects.

The main difference between social anthropologists and materialists is the difference between how they regard social and economic phenomena, and this in turn affects what each school proposes can be illuminated with an economic approach. Social anthropologists take the view that social phenomena cannot be studied economically because social behavior subsumes economic behavior and, as such, an economic approach is ill-equipped to shed light on the more general and encompassing society. Materialists, on the other hand, do not accept the premises established by social anthropologists. The materialists, from the very beginning, deny that economic behavior is subservient to or subsumed by social behavior; that is, the materialists do not consider the economic realm to be contained within the social realm. As such, the materialists cannot be accused of being reductive; and therefore shedding light on social matters via an economic approach, according to the materialists, is possible.

Social Exchange

Social exchange advocates, such as Barth (1967), Belshaw (1968), and Salisbury (1969) take the materialist thesis one step further than the materialist economic anthropologists do (Schneider 1974:17-18). Whereas the materialists propose that material and *probably* nonmaterial products can be treated with a formal economic approach, the social exchange anthropologists are adamant that nonmaterial can be treated formally with economic theory because economic behavior governs social behavior. In other words, social behavior *is* social exchange. Most if not all social behavior, claim the social exchange theorists, is economic at its core regardless of the appearances.

Altruism in economic transactions does not exist, regardless of appearances. This notion is structuralist in that it claims that there exists a core of very basic rules operating beneath the veneer of what we take to be one's demeanor. For example, an individual in a given society may appear to be completely selfless as he gives his goat to his neighbor. But beneath this act, the social exchange theorists propose that there is a profit-motivated incentive to the act. This profit-seeking incentive has only to be identified, which in many cases is not easy. In some cases, it seems that individuals cover up selfish characteristics in order to make themselves look good *personally.* In other cases, it appears to be a custom and therefore a *social* characteristic to hide one's selfish side.

According to social exchange theorists, the reason that the social anthropologists see economic behavior in the context of social behavior is because social behavior is all that is seen in many instances. When the anthropologist observes people, the anthropologist is observing the visible aspects of human life, such as the customs. In this situation, the social exchange advocates would say that the social anthropologists have been misled into believing that the social is determining the economic because it is all that is observed. According to the social exchange theorists, if one was to look beyond or beneath the social, one would irrevocably come to the conclusion that there exists in every social act an economic motive. This economic motive, like Radcliffe-Brown's (1957:131) *principle of justice*, is a universal law of equivalent returns. It simply states that anything that *ego* gives to *alter* is returned to *ego* according to some function of what was given. In other words, nothing is given without receiving something in return, whatever that "something in return" is.

The social anthropologist sees only what is given, whereas the social exchange advocate sees both what is given and what is returned. The undeniable conclusion for the social exchange theorist is that society is built on exchange and therefore on economic motives.

4.1.4 The Kind of Economic Approach Taken Here

Next, I will describe the economic approach that I will take in modeling my case study of Classic Maya exchange and situate it theoretically in the context of what was just discussed.

The approach that I will take is economic in all senses of the word "economic". As has been discussed, there are two prevailing economic approaches in anthropology and archaeology: substantive and formal. Both views contrast significantly, yet they both can be regarded as economic approaches. The approach I take in modeling my case study of ground stone exchange in the Maya Mountains — specifically the exchange behind the movement of manos and metates along the Bladen Branch — is essentially formal; however, the approach does have some substantivist characteristics, which I discuss below.

My approach to modeling the exchange of ground stone tools among the Maya Mountains communities utilizes two *formal* economic concepts:

1. The model is mathematical. It uses logical symbols, such as variables and parameters to denote states and constraints, and the purpose of the model is to determine the frequency of ground stone implements per household at each of the sites (i.e. demand). To be precise, the *variable* (fluctuating quantity) in the model will represent the number of ground stone implements per household, whereas the *parameters* (constants) in the model will denote the magnitudes of growth and interaction.

2. The model is based on the notion that demand for manos and metates indirectly generates a supply for the manos and metates. I use the term *indirectly* since there are of course other considerations such as how the use-value of manos and metates compares with the use-values of other goods that could be obtained in the marketplace.

There are aspects of the approach that I use, however, that can be considered to be *substantive*:

1. The mathematical model that I construct is adapted from macroeconomics and, as such, it is flexible and can therefore be tailored to practically any economy. This is because macroeconomic models incorporate statistics from the economies that they model (Schneider 1974:43). In other words, macroeconomic models can be fitted to a given economy by utilizing information from the specific economy being studied — in my case Classic Maya exchange — and adjusting the model to fit the specifics of the economy. The economic model therefore is inductive in

nature.[6]

2. The model I construct depicts the economic behavior of an entire society as a system. However, unlike the substantivists, who envision the social or economic system as something needing to be maintained (in equilibrium) by the members of that society, I make no *a priori* assumptions as to the system's stability.

To conclude this discussion, I will simply state that the economic approach I take in modeling Classic Maya exchange in the Maya Mountains is formal with some substantive characteristics. In other words, while my method is formal with regards to its mathematical foundation and its notion of supply and demand, the model is substantive, since it is tailored to the specific case of ground stone exchange in the Maya Mountains.

In addition to my economic approach being closer to the formal end of the continuum than the substantive end of the continuum, the entire enterprise of this thesis in which I demonstrate the cognitive implications of the approach is deductive. The deductive aspect of my thesis becomes clear in Chapters 7 and 8.

4.2 Classic Maya Lowland Exchange

Classic Maya lowland exchange is generally divided into four cross-cutting categories of exchange: exchange of utilitarian goods, exchange of non-utilitarian goods, regional exchange, and long-distance exchange (Sharer 1994:452-453).

[6] My statistics come from the archaeological record as well as from previous research into how the ancient Maya exchanged goods.

In past Maya archaeological research, it was often the case that most goods traded in the lowlands, whether utilitarian or non-utilitarian, were regarded as having come from the highlands to the west or from the Caribbean coast to the east (Rathje 1973). From the highlands it was possible to obtain hard stone materials for making stone tools such as *manos* and *metates* for the grinding of seeds and grains into flour, and obsidian for the manufacturing of blades. From the coast it was possible to reap the benefits that the sea had to offer such as salt and dyes that can be made out of certain mollusks.

In either case, most goods appeared to have come from afar, leading Rathje (1973) to propose that the Maya lowlands were a resource deficient zone. In this model, *select* sites in the lowlands would have functioned as the recipients of long-distance trade and as redistribution centers; goods that were sent to the redistribution centers would have then trickled down to satellite sites around the redistribution centers. Such a model would have left little reason for the smaller sites around the redistribution centers to interact with each other as far as goods were exchanged.

Much work since then has shown this model to be inadequate due to the realization that the lowlands is not as geologically, zoologically, or botanically homogeneous as previously believed (Graham 1987; Shipley and Graham 1987; Dunham *et al* 1992-2000; Abramiuk 2002, 2003). One such geologically and biologically diverse region in the lowlands is the Maya Mountains, which contain distinct minerals and biota that were important in the manufacturing of goods for trade.

The picture now painted is that products exchanged in the Classic period could have had their origins in the lowlands as well as the highlands and this has direct effects on how we conceive of exchange. No longer are the sites surrounding the redistribution center, portrayed in Rathje's (1973) model, dependent on the center for exchange. Sites surrounding the redistribution centers were also involved in their own regional exchange that supplied individuals with goods and services, which was largely independent of the overarching center (McAnany 1991:282-283; Graham 1994; Abramiuk 2002, 2003).

Such a model would be consistent with the ethnohistoric data from areas outside the lowlands, namely the Quiche Maya of highland Guatemala (Carmack 1981:153-154) and the Aztecs of central Mexico (Smith 2003:106-112). Though there were undoubtedly direct dealings between producers and buyers, much exchange conducted by the Quiche Maya and Aztec was held in markets, which were largely independent of state control (Carmack 1981:154; Smith 2003:123). Though archaeologically it is difficult to recognize market places that would have functioned as the centers of economic life for the ancient Maya (Sharer 1994:456), Classic Maya market places for at least some trade goods have been identified (Blanton *et al* 1993:182).

For the Aztecs and the people of the empire, exchange was conducted by part-time traders/farmers and by full-time merchants and the state was only involved in settling disputes that might arise in market dealings (Smith 2003:106-112). Like Aztec exchange, Quiche Maya exchange was also conducted by full-time and part-time merchants. Full-time merchants were a class of individuals wedged between a stratum of lords who occupied a higher position and a stratum of vassals (commoners) who occupied a lower position in the social hierarchy, whereas the part-time merchants were commoners (Carmack 1981:153-154).

The Quiche exchange system was more regulated than the Aztec exchange system. For example, Quiche warriors guarded access into and out of their cities (Carmack 1981:196-198) and probably charged tribute for using the roads and market places (Carmack 1981:153). Whatever the case may have been, it is quite certain that many of the merchants that traded in the markets paid tribute to lords in the towns and cities that the merchants traded in. In return, the lord would provide the merchant with room and board for the length of the merchant's stay. The merchant was also obliged to pay tribute to certain lords in the town or city from which the merchant came. In both cases, this tribute acted as a tax of sorts, which benefited the elite in the merchant's home community and in the merchant's destination community. In this way, all levels of society benefited from exchange: the commoners who exchanged items in the marketplace with the full-time or part-time merchant, and the elite who were paid tribute by the merchant outside of the market setting.

From the ethnohistoric evidence it is highly suggestive that merchants frequently had direct involvement with their buyers, whether it was paying tribute to the lord of a community or selling something at the market with a commoner. This suggests a kind of freedom or entrepreneurship that could be granted to the merchant without the pressure of an overarching political obligation. The merchant in both situations was not obliged to take his or her goods to a specific market; the incentive appeared to come from the merchant himself.

As was mentioned above, being a merchant was not necessarily a full-time job and with regard to inter-community commerce among communities within a few kilometers of each other, it was very likely that commoner households did much of the manufacturing and selling of their own products (Carmack 1981:154). These commoners, or vassals as Carmack (1981:148-150) calls them, paid tribute to the lords on whose land they lived. Commoners, however, were free to engage in many activities as long as they paid tribute to their lords both in terms of subsistence and goods that would have been obtained at the local markets. A commoner's main concern was working the fields and any other activities, such as production and exchange of goods, had to be done in the commoner's spare time away from the fields. For the Quiche Maya (Carmack 1981:154), the commoner class was undoubtedly responsible for much of local trade, whereas full-time merchants were involved in long-distance ventures.

4.2.1 The Formal Approach to Exchange

In the most general sense, exchange is the process in which one gives something and in return for giving, one receives something. For both actors involved in the transaction, it is assumed that the motivation behind the exchange is to be "better off" in one form or another for having done the transaction. This could mean that one gains a quilt while losing a projectile point, or it could mean that one gains the right to open a stall in the market place while losing certain goods or services through tribute. It can even be argued that gift-giving is the expectation that the giver will be given a gift some time in the future in the form of a material object or a service (Mauss 1990:73-76). At the time that the transaction is being conducted, there is, behind the transaction, the notion that one is getting something for giving something. Classic Maya exchange, from what has been described above, seems to be motivated by this concept.

I would agree with the substantivists that the motivation behind exchange is not necessarily conducted for material gain as it is usually taken to be in modern western society, but there is at least a non-material or qualitative gain from the economic transaction. Such a definition of exchange could subsume even the substantive claim that exchange is conducted for the sake of maintaining the social system. In this sense, the gain could even be a conversation with someone, which was certainly true of the Aztecs (Smith 2003:111-112).

4.2.2 The Forming of Bonds Through Exchange for the Classic Maya

In view of the proposal that exchange is an opportunity to gain something, the Classic Maya merchant would have exchanged through two means: through communication between the buyer and seller and the through the intrinsic properties of the good. They are not separate means but two means that work together. This is consistent with Renfrew's (1984:103-105) observations.

The bond created between seller and buyer greatly facilitates the seller and, in many cases, the seller's community in gaining a reputation for the individual or the community, respectively. This reputation, in turn, facilitates the production of goods since there will be more demand for the goods. During the act of exchange, the buyer recognizes and identifies the seller and, through association, the seller's community (assuming the good comes from the seller's community) as the source of the good that the buyer is buying. Such recognition and identification functions as a social-economic bond between the buyer and the seller if the buyer likes the good that the seller has sold to the buyer. As a result, the buyer may maintain the bond between himself or herself and the seller and may even pass on a good word about the seller to other potential buyers in the buyer's community. This could, in turn, develop into more clientele for the seller or for the seller's community (if what the seller is selling becomes identified with the seller's community).

Even more important than the buyer-seller bond is the intrinsic properties of the good itself as a means through which exchange takes place. In other words, the good itself is just as useful for the seller and possibly for the seller's community as a good word from a buyer to his peers.

If the good being produced is identified with some communal characteristic then the demand for that good extends beyond a given seller and includes all of the sellers from the same community because the object is associated with something inherent in the community. This, of course, would differ from a good that involves much personal craftsmanship and can therefore only be identified with a particular seller. Below, I have provided two examples of these two kinds of goods:

- An example of a good that is frequently associated with a producer's community — what I refer to as a *communal* good — is a mano and metate since it often has distinctive characteristics that can be attributed to a community. In this case, the color and composition of the rock used to manufacture the mano and metate can reflect specific regions or communities. For instance, I argue in Section 5.4.3 that the manos and metates being exchanged among the Bladen communities are communal goods.

- An example of a good that is frequently associated with an individual producer — what I refer to as a *personal* good — is a polychrome vessel, since polychrome vessels often have distinctive features that can be attributed to a particular producer. That is, a signature or stylistic embellishment can be attributed to a specific artisan.

In this sense, every good can be seen to have features that one associates with an individual or a community of individuals. Those features of a good that can be attributed to a community are features that will cause potential buyers to gravitate toward any group of sellers from a particular community, whereas those features of a good that can be attributed to an individual are features that will cause potential buyers to gravitate toward a particular seller. In the case of a communal good, the buyer's attention is on a particular community and in the case of a personal good the attention of the buyer is on a particular individual.

I will mostly be concerned with communal goods, particularly since I am interested in the exchange of manos and metates. The manos and metates of the Bladen are communal since, as I have already mentioned above, they reflect properties that can be attributed to all sellers from a certain community rather than to a particular seller. Since this kind of exchange manifests itself as inter-community exchange rather than inter-personal exchange, something must be said about the way that communities interact with each other. This will be the subject matter of the next section.

4.3 Classic Maya Inter-Community Exchange

Much about Classic Maya inter-community exchange can be extrapolated from the manner in which communities interacted with each other politically. Classic Maya communities were part of a political hierarchy, just as individuals are part of a social hierarchy in a stratified social structure. Much of our knowledge of Classic Maya political hierarchy has developed out of studying epigraphic data from Classic Maya polities (Culbert 1991). Polities are defined as the highest ranked communities in a given society and the interaction between polities is referred to as peer polity interaction (Renfrew 1986).

4.3.1 Peer Polity Interaction

Peer polity interaction (Renfrew and Cherry 1986) can be defined as a process by which autonomous polities relate to one another and in so doing develop together. As a result of this process, peer polities frequently acquire the same *structural* features, such as the same types of administrative organization, religion, and language. Peer polity interaction is a means of explaining the emergence of a culture through the interactions of like political entities, instead of through external causes such as diffusion or internal causes such as administrative changes.

Diffusion falls under the category of explanations which attribute causes of social phenomena to *exogenous change* (Renfrew 1986:5-6). Exogenous change is usually used to explain the emergence of a culture at a given site through the community's contacts with foreign political powers. In this view, specific social institutions within the community in question are derived from a dominant neighboring community or groups of communities. In this way, the community being considered is simply a *secondary* development of the external communities which are generating the ideas for their neighbors.

The cause behind the emergence of a culture cannot always be regarded as coming from outside the community being considered, because culture change can sometimes be attributed to processes occurring within the community (Renfrew 1986:6). In these cases, the emergence of a culture and of social phenomena in general are the result of *endogenous changes* within the community. These changes can be the result of revolutions or innovative charismatic leaders, but in any case the spark of ingenuity which brings about the culture change is internal.

As defined by Renfrew (1986:6-7), peer polity interaction contrasts with both exogenous and endogenous change explanations in that it explains the emergence of a culture as the result of intermediate interactions. Peer polity interactions are not the long-distance relations that are frequently associated with goods and information entering a site from a primary state. Nor are peer polity interactions the results of political dynamics occurring within the site. Rather peer polity interaction is a theory that attributes the growth of a culture to the free flow of goods and ideas among sites of the same or roughly the same political scale.

Peer polities that interact are frequently *structurally homologous* (Renfrew 1986:4-5), since the free flow of information and goods between the polities has resulted in the establishment of similar social institutions. This means that the polities will often share the same cultural features, whether these features are language, settlement patterns, architectural similarities, or religion. Regions where peer polity interaction seems to be an important factor in promoting change, to name two, are the Greek islands during the first millennium B.C. (Renfrew 1986:10-15) and the Classic Maya (AD 300-900) polities (Freidel 1986; Sabloff 1986).

What makes two polities peers is that they must be autonomous political entities that are analogous in scale (Renfrew 1986:4). Such polities frequently occur in close proximity, neither dominating the other (Renfrew 1986:1). It is important that the polities being considered are close enough to each other to interact. This is because the emergence of structural homologies that constitute a culture depends on a free flow of information and goods between polities, and this flow is frequently dependent on the distance or ease of travel between the polities.

Peer polities are rarely in a situation in which one is dominated by the other for a significant length of time. The relation formed in such a situation would result in a dominant/subordinate relationship, which is clearly not a relationship in which both polities interact as peers. Nevertheless, as Renfrew (1986:2) discusses, it sometimes occurs that a peer relationship does turn into a dominant/subordinate relationship, for this is how empires or nation states are formed.

4.3.2 Types of Peer Polity Interactions

Very important in peer polity interaction studies is the nature of the interactions or relationships between polities and how these interactions motivate the development of a culture. Renfrew (1986:8-10) describes the kinds of relationships which frequently arise among communities engaged in peer polity interaction as: warfare, competitive emulation, symbolic entrainment, transmission of innovation, and increased flow of the exchange of goods.

It is the *flow in the exchange of goods* as a form of interaction among polities that I will be mostly concerned with in this thesis. Another form of interaction that will be important is *symbolic entrainment*, which I argue in Sections 5.8 – 5.9 was structuring the manner in which ground stone goods flowed among the Bladen communities.

1. One way polities interact is through warfare (Renfrew 1986:8). Warfare on a sustained basis functions as a conduit through which cultural information can be transmitted or reinforced from polity to polity. Warfare can also strengthen administrative institutions that are directly or indirectly in charge of organizing attacks on neighboring polities, thereby stimulating political and cultural complexity.[7]

2. Competitive emulation entails public displays such as the construction

[7] Freidel (1986) discusses the importance of warfare in the peer interaction among Classic Maya polities.

of monumental architecture and other symbols of status and power in order to outdo or impress the other polities in the region (Renfrew 1986:8). This competitive behavior results in increased political growth and structural homologies because competition entails beating the opponent at similar tasks. In this way, if a particular form of architecture is raised at one polity, the same architectural form, which might be improved upon, will be constructed at another polity (e.g. Rathje 2002).

3. Symbolic entrainment involves the adoption of a more developed symbolic system in place of a less developed symbolic system (Renfrew 1986:8-9). In this case, polities of equivalent status but with different symbolic systems will move towards utilizing the most efficient symbolic system. Thus, a polity with a less developed symbolic system will usually adopt the more developed symbolic system from the other polity. Such a symbolic system might be a certain administrative procedure, a government, or a writing system.

4. Transmission of innovation is similar to symbolic entrainment with the difference being that the innovation being transmitted is not symbolic (Renfrew 1986:9-10). Such an innovation might be technology, for example. In this scenario the transmission of an innovation results in that invention, whatever it may be, being used at both the polity that generated the innovation and the recipient polity.

5. An increased flow in the exchange of goods can cause polities to develop better administrations for dealing with the intensified imports and exports of goods (Renfrew 1986:10). Peer polities involved in exchange require facilities for dealing with the influx of traders with their goods. In this manner, the infrastructure for coping with transactions leads

to the growth of economic capital. Increased flow in the exchange of goods and its effects on the development of social institutions has been observed in Mesoamerica (Blanton *et al* 1993:208-217).

Why it is exactly that a polity would want to interact with its peer (i.e. another polity with similar status as itself) is an interesting question. Lin (2001:45) proposes that there would have been a natural tendency for polities to interact with like polities — to form homophilous relations with each other. This natural tendency to associate with like parties is called the *principle of homophily* or like-me hypothesis (Homans 1950; Lazarsfeld and Merton 1954; Laumann 1966; Lin 2001:39) and was investigated as a mechanism for generating cultural patterns by Axelrod (1997) and Kennedy (1998) (see Section 2.4.2).

Lin (2001:48) explains that the action involved in maintaining one's status as a peer (*expressive action*) involves less work than the action involved in gaining status from one higher in the social organization (*instrumental action*) (Lin 2001:48). In terms of a polity maintaining its political status, engaging in homophilous relations with peers would be optimal because it would have the lowest cost-benefit ratio of the two options.

4.3.3 Classic Maya Peer Community Interaction

For the Classic Maya, social stratification did not just exist at the scale of the individual but it existed at the scale of the community. That is, the Classic Maya were part of a political hierarchy of sites. Marcus (1973:911) adopted the term "cognized model" from Rappaport (1971:33) to refer to the mental picture that Maya individuals would have had of their universe. Based on this cognized model, Maya individuals living in the Classic period would have had a good idea of a community's power or standing (e.g. they would have known which community was of a different rank and which community was a peer). Marcus (1973) points to epigraphic data to support this conception of Maya society, which most Classic Maya would have shared.

Marcus' (1973) Cognized Model of Classic Maya Politics

According to Marcus, the Maya envisioned four polities, which functioned as overlords for the rest of the communities in the Maya world. For long periods of time, these paramount centers functioned as peer polities. However, their statuses as peer polities were subject to change. Reasons for changes to the cognized political hierarchy might be the defeat of one of these polities by an underling, a plague, or economic ruin. Two important inscriptions bear out how the cognized model could change: the inscriptions on Stela A at Copan and the inscriptions on Stela 10 at Seibal.

1. In the inscriptions from Copan, dated to A.D. 731, four emblem glyphs designate the principal polities of Copan, Tikal, Calakmul, and Palenque as the four *bacabs* that, according to Classic Maya religion, held up the cosmos.

2. At Seibal, Stela 10, dated to A.D. 889, describes Seibal, Tikal, Calakmul, and Motul de San Jose as the new *bacabs*.

In the second inscription, the sites of Copan and Palenque seemed to have dropped out of the running as paramount powers in the Maya realm and were duly replaced by Seibal and Motul de San Jose. This indicates that a polity could fall out of peer status with the its cohorts at anytime due to some devastating blow to the polity. Such a blow seemed to have impacted Copan and Palenque sometime between A.D. 731 and A.D. 889, marking the beginning of the Classic Maya collapse during the Terminal Classic (Martin and Grube 2000:18).

From this as well as other epigraphic evidence, Marcus (1976:46) proposed that the Classic Maya accepted a hierarchical arrangement based on several principles of which I will only mention four:

1. The first principle is that primary centers had their own emblem glyphs and could refer to other primary centers in the inscriptions on their stelae.

2. The second principle is that secondary centers, which were the dependencies of the primary centers, have their own emblem glyphs and frequently refer to their associated primary centers, though the reverse, whereby primary centers refer to secondary centers, rarely happens.

3. The third principle states that tertiary centers only refer to their associated primary and occasionally their associated secondary centers.

4. The fourth principle states that quarternary centers do not have emblem glyphs of their own and do not mention any other centers.

In Marcus's (1976) view, Maya political hierarchy had its roots in the primary center or *polity*. The polity's subordinate centers did not refer to centers connected to a different polity; they only referred to centers dominated by the associated regional polity. The exception to this rule was, of course, the polities themselves who could mention any center. These principles acted as political guidelines for the centers, yet it appears not to have stopped freedom of movement up the hierarchy. Seibal, for example worked its way from being a tertiary center to a primary center by A.D. 889 (Marcus 1976:74). Still, this rigid model permitted little recognition in the hieroglyphic record of interaction between communities below the status of primary center.

Beyond Marcus' (1973) Cognized Model of Classic Maya Politics

Today, our perspective on the hierarchical arrangement of Classic Maya communities and on how communities interacted with each other has been further illuminated (Martin and Grube 2000:18). For example, evidence now suggests that regardless of what status communities had, they nevertheless interacted with each other. In other words, the notion of what constitutes *being a peer* is relative. Not only could primary centers have peers, but so could secondary and tertiary centers have associated peers. It is still agreed that a political hierarchy existed for the Classic Maya, but the notion of being peer exists for all communities at all levels in the political hierarchy, not just polities. This evidence comes in the form of new epigraphic data demonstrating that relationships did exist among peer communities below the level of polity.

A good example of how our view of the Classic Maya political hierarchy has changed from Marcus's research is her proposal that Piedras Negras and Pomona are secondary centers. According to Marcus's principles of hierarchy, they should not refer to each other in their inscriptions, but in fact they do. These centers had two conflicts and an unknown contract between them (Martin and Grube 2000:21). Inter-community relations manifested themselves everywhere in the hierarchical arrangement of centers and peer interaction between centers below the level of polity was no exception. In short, peer interaction manifested itself within the different ranks of the Classic Maya political hierarchy, and not just within the highest rank.

Homophilous relationships (i.e. relationships among entities of the same rank) among communities were by no means the only kinds of relationships that pervaded Classic Maya politics, heterophilous relationships (i.e. relationships among entities of different ranks) did too. In fact, the Classic Maya political landscape could be regarded as one in which communities had changing relationships with their peers. However, in cases in which communities on equal scales interacted with each other, the notion of being a peer was integral in strengthening relations among the communities and structuring the dynamics of inter-community interaction.

4.4 Conclusion: The Economic Approach to Classic Maya Exchange

The economic approach that is to be taken in mathematical modeling of Classic Maya exchange in the Maya Mountains has been the main concern of this chapter. I have situated my approach in the economic anthropological literature and have found it to be mostly formalist with aspects of substantivism. In addition to the formalist emphasis, the thesis itself is deductive in that its aim (in Chapters 7 and 8) is to show how the utilization of a substantive model can contribute to making small advances toward a theory of cognition.

The substantivist aspects of my model can be inferred from ethnohistoric, ethnographic, archaeological and geological data, which I have only touched upon in this chapter, but will elaborate on in more detail in the next chapter. The formalist aspects of my model are that the model I construct is mathematical and is based on the notion that demand for manos and metates indirectly generates a supply for the manos and metates. This demand for a good is, in turn, influenced by: 1) other goods that can be obtained in the marketplace as well as by 2) what kind of good it is that is in demand.

With regard to the first point, why a particular item is chosen over another item is often dependent on what is offered at the market and this, of course, is an issue of how the use-value of one good compares with the use-value of another good. For example, a good that is surrounded by goods that can serve the same purpose as the original good is not nearly as valuable as a good that has no other substitutes. With regard to the second point, why we choose to buy something from someone rather than someone else is often influenced by whether the good is a personal or communal good. A personal good can only be bought from a particular artisan, whereas a communal good can be purchased from any number of artisans from a particular community. In studying the Bladen exchange system, I concentrate on modeling the exchange of a communal good, namely ground stone (i.e. manos and metates). Communal goods are goods that have distinct characteristics that can be attributed to a community, as explained above.

In order to construct an accurate model depicting Classic Maya inter-community exchange dynamics, it has to be taken into consideration that the Maya adhered to a political hierarchy in which communities were grouped. Some communities naturally fell into the same group or rank and were regarded as peers. The notion of being a peer among communities of the same rank, especially among those of the highest rank, is believed to be an important factor in the rise of many civilizations (Renfrew 1986) including Classic Maya civilization.

As Marcus discusses, being a peer constituted a set of "cognized" rules, which the Classic Maya would have been attuned to and which would have had a direct effect on how communities interacted. Peer communities interacted with each other differently than they did with communities that were higher or lower on the hierarchical pyramid. Peer communities interacted in such a way that they pulled "each other up up by the bootstraps" (Renfrew 1986:11). Being equals, a movement of resources between and among peers would have represented a more or less equitable transfer which would have tended to strengthen relations between peers. This contrasted with non-peer relationships such as tribute obligations in which transfers of resources from one community to another were not equitable and therefore might not strengthen relations. When communities interacted with communities out of their peer class, the interactive dynamics among the communities also changed. In my case study in the Bladen region, I concern myself with exchange among peers and how the notion of being peer symbolically structures inter-community exchange. This is because the communities in the Bladen region, which I will be studying in the next chapter, were peer communities, which shared a symbolic system which affected the manner in which exchange was conducted.

Chapter 5

The Bladen Branch Case Study

My case study is a Late-Terminal Classic inter-community exchange network which has been defined as the result of fieldwork and laboratory analysis that I conducted throughout 2001 and 2002. The inter-community exchange network was reconstructed archaeologically by tracking the movement of ground stone grinding implements (manos and metates) among three sites along the Bladen Branch in the southern Maya Mountains of Belize. This is the first inter-community ground stone exchange network to have been reconstructed in the Maya area.

The Purpose of the Bladen Case Study for the Thesis

The Bladen exchange case study serves an important theoretical and methodological purpose. The purpose of the Bladen case study, which is presented in this chapter, is to use archaeological material to contribute in *building theory* about supra-individual cognition. The notion of theory building was discussed in Section 4.1.2.

To be more specific, the purpose of studying ground stone exchange along the Bladen Branch is to show that Bladen exchange constituted a *dynamical* *system* and indeed a *cognitive system*. The reader should recall that a major theme running through Chapter 3 was that cognitive systems are dynamical systems. Therefore showing that something is a cognitive system entails showing that that it is first and foremost a dynamical system which occurred or is occurring in the natural or social environment.

Demonstrating that Bladen exchange constituted a cognitive system will allow me to contribute to the theory of cognitive systems and to take steps toward a comprehensive theory of cognition which includes social phenomena. My conception of cognition maintains that social systems can be conceived of as cognitive systems. This means that my conception of cognition can potentially be extended to explain aspects that are generally considered to be social issues studied by social theorists and scientists.

5.1 The Two Aims of the Bladen Case Study

The beginning of systematic archaeological research into resource exploitation within the Maya Lowlands was initiated by Graham (1987). Using the results from petrographic analyses conducted by Webster Shipley, it was shown that several manos collected from the central Lowland sites of Uaxactun and Seibal came from the Maya Mountains (Shipley and Graham 1987). Not only did this research shift some of the attention that was placed on the resources of the highlands (Thompson 1963, 1964; Rathje 1972) to the resources of the lowlands (Graham 1987, 1994; McKillop 2002), but it suggested that if enough was known about the geology around communities, ground stone artifacts throughout the Maya realm could be traced to specific source zones which in turn might be linked to individual communities (Graham 1987). In this manner, through detailed provenance work, exchange networks could be reconstructed and, as a result, much could be learned about socio-economic relationships between communities. The first aim of this study demonstrates how such an inter-community exchange network was reconstructed in the Maya area using ground stone as a medium of exchange.

To reconstruct ground stone exchange networks at the level of specificity proposed by Graham (1987) — that is, at the level of the community — intensive investigations of the geology surrounding archaeological sites located in potential resource "hot spots" needed to be conducted. The "hot spots" that were chosen to be investigated were the Mountain Pine Ridge granites, the Hummingbird granites, the Cockscomb-Sapote granites, and the Bladen volcanics (Graham 1987).

In 1992, the Maya Mountains Archaeological Project (MMAP) was launched in the area of the Bladen volcanics. Directed by Peter Dunham and funded by the National Geographic Society, the purpose of the MMAP was to locate ancient Maya communities that played key roles in exploiting geological and biological resources and in exporting products made from these resources to communities outside of the Maya Mountains. As a result, extensive archaeological and geological investigations by the MMAP have been undertaken throughout the southern Maya Mountains of Belize, primarily along the Bladen Branch (Dunham *et al* 1992-2000). The outcome of these investigations has yielded eighteen previously unrecorded sites and a vast comparative rock collection for the southern Maya Mountains, which is currently housed at the Department of Geosciences at the University of Houston (Dunham *et al* 1992-2000). It was at the Department of Geosciences under the supervision of Dr. William Meurer (also the MMAP geologist) that I conducted the petrographic analysis needed to reconstruct the Bladen exchange network for this study.

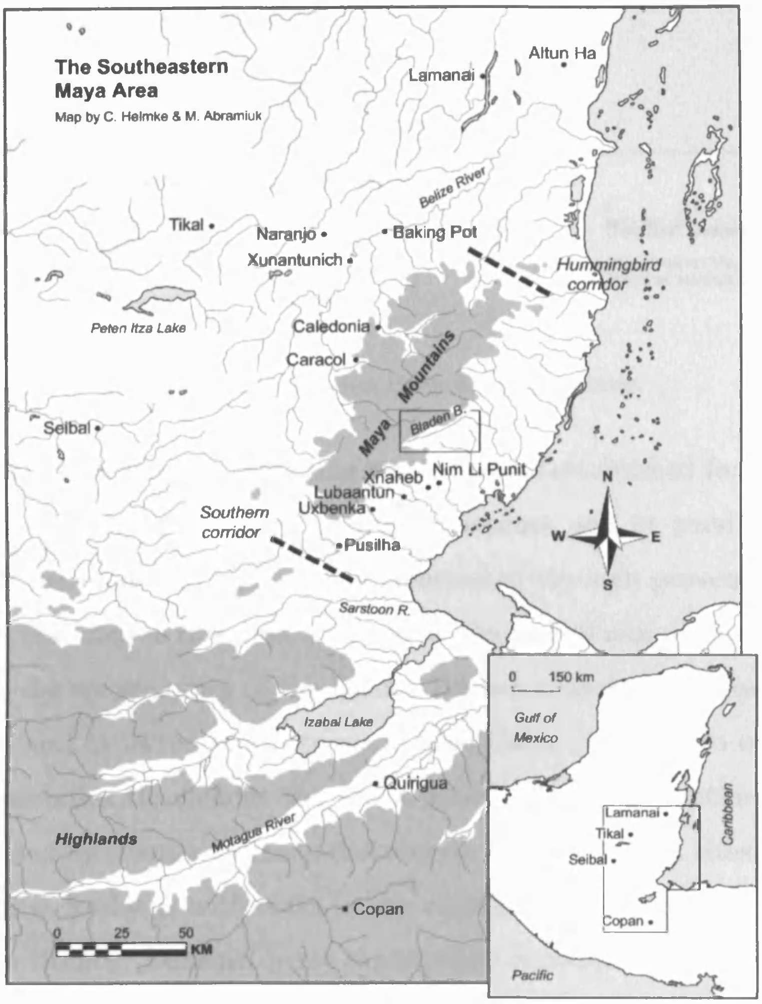

Figure 3: The Bladen region of the Maya Mountains and the surrounding Maya area.

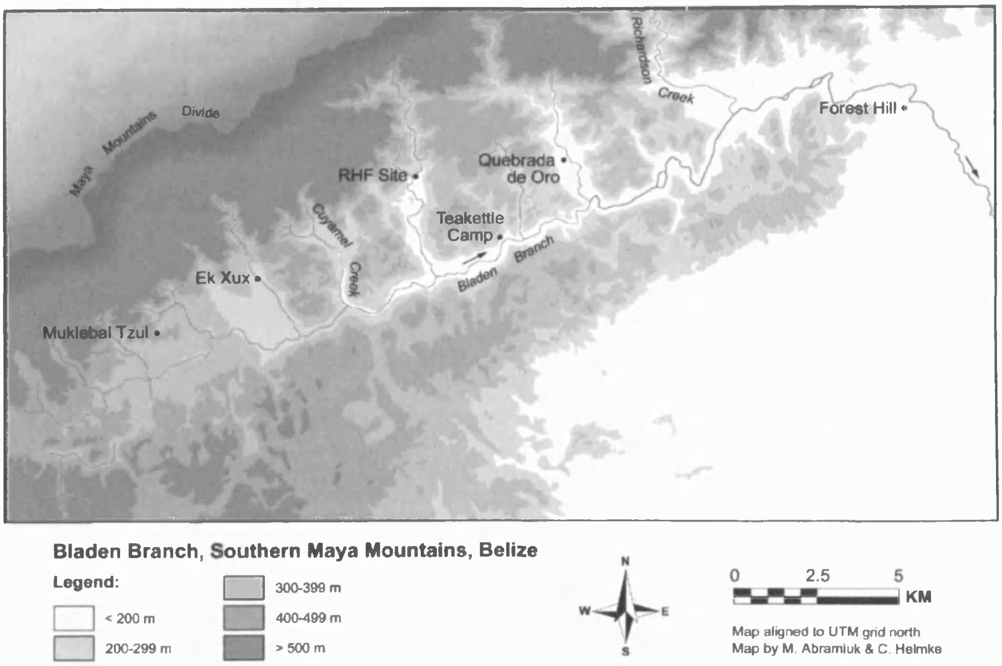

Figure 4: The Bladen Branch communities.

While the potential for exploiting resources was established for the Maya Mountains communities, export of these resources and or products made from these resources still had to be demonstrated through provenance analyses. As a first step in this direction, and as the second aim of this section, I show that the communities of the Bladen Branch exploited the resources in the region and exported products made from these resources to other lowland communities throughout the Maya realm. These connections will be demonstrated by comparing mano and metate fragments from sites throughout the Maya lowlands with rocks in the vicinity of four communities along the Bladen Branch. Demonstrating exploitation and export are important in supporting certain assumptions that are made with regards to reconstructing exchange networks.

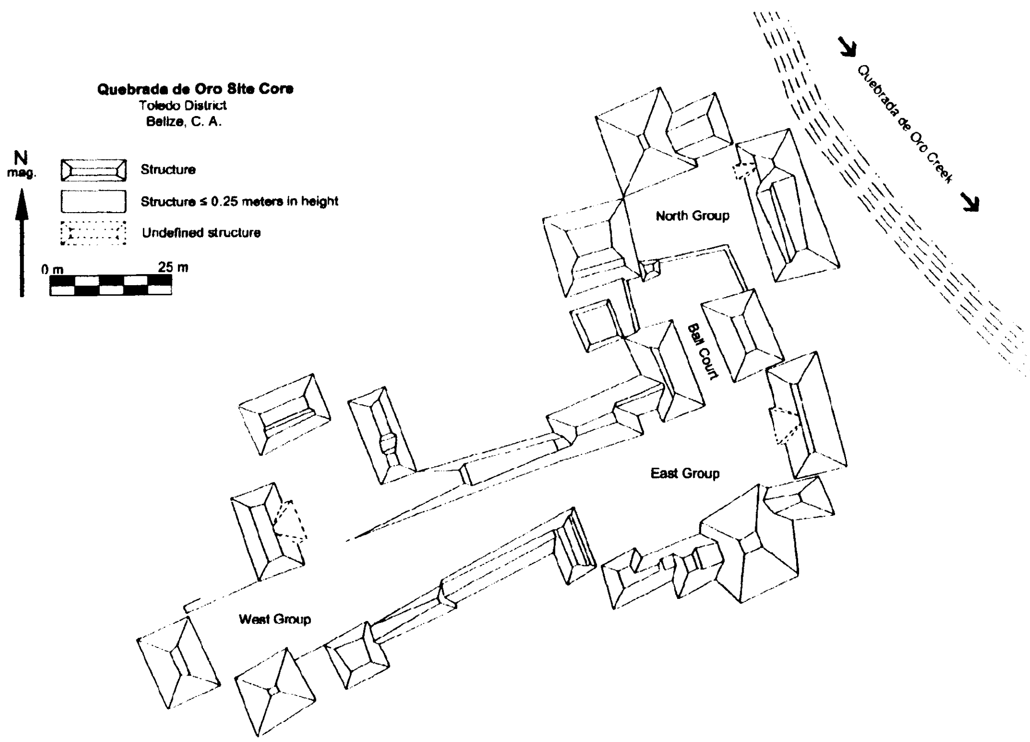

Figure 5: The Quebrada de Oro site core (map after Dunham *et al* [1993]).

5.2 The Bladen Communities

The present research focuses on four sites along the Bladen Branch in the southeastern Maya Mountains and the different rock resources that the sites exploited (Figure 3). The first site that will be investigated in this study that is farthest down river but still within the Maya Mountains proper is the Quebrada de Oro Ruins located in the Quebrada de Oro; upstream from this is the RHF Site located in the Ramos Quebrada, and moving further upstream from this site are Ek Xux and Muklebal Tzul, located in the Ek Xux and Muklebal valleys, respectively (Figure 5).

Radiocarbon dates from cultural contexts place the sites of Muklebal Tzul and Ek Xux mainly in the Late and Terminal Classic Periods (A.D. 600-900), with sparse Postclassic activity, and limited Early Classic activity at Ek Xux (Kindon 2002:269; Prufer 2002). The Quebrada de Oro Ruins and the RHF Site are also dated to the Late and Terminal Classic based on layout and architectural features of the sites (Dunham *et al* 1993). Taken together, the evidence suggests that all four sites share a Late-Terminal Classic component, indicating that they overlap temporally, and therefore can be regarded as contemporaneous communities. Subsistence studies suggest that the Late Classic population growth spurt at one of the sites, namely Ek Xux, was relatively short-lived, approximately 150-200 years (Abramiuk 1998). This estimate assumes that the developmental cycle (Goody 1969; Tourtellot 1988) was in effect at Ek Xux, that an agricultural strategy was utilized at Ek Xux that involved both intensive methods of cultivation (i.e. raised fields) as well as non-intensive methods of cultivation (i.e. slash-and-burn), and that Culbert's (1988) carrying capacity estimates associated with these methods of cultivation are appropriate. Ultimately, more excavation will be required to ascertain the precise ranges of occupation for the four sites. However, the present evidence indicates that all sites were contemporaneously occupied in the Late and Terminal Classic.

All four Bladen sites are modest in size with the largest structures being around 3.5 meters in height. For the most part, the Bladen sites have well-planned site cores with causeways connecting plaza groups. Typical of Classic Maya centers, all of the Bladen sites with the exception of the Quebrada de Oro Ruins have stelae. Unique to the Quebrada de Oro Ruins, however, is the fact that it contains a ball court.

The stelae at the Bladen sites bear no inscriptions. Therefore, with the exception of a few ceramic sherds from Muklebal Tzul with glyphs (Prufer 2002), very little epigraphic information regarding these communities exists. The presence of certain settlement features at the sites, namely the stelae and well-planned site cores traditionally associated with Classic Maya polities, suggest that the Bladen communities saw themselves as politically autonomous. However, this still does not rule out the possibility that these

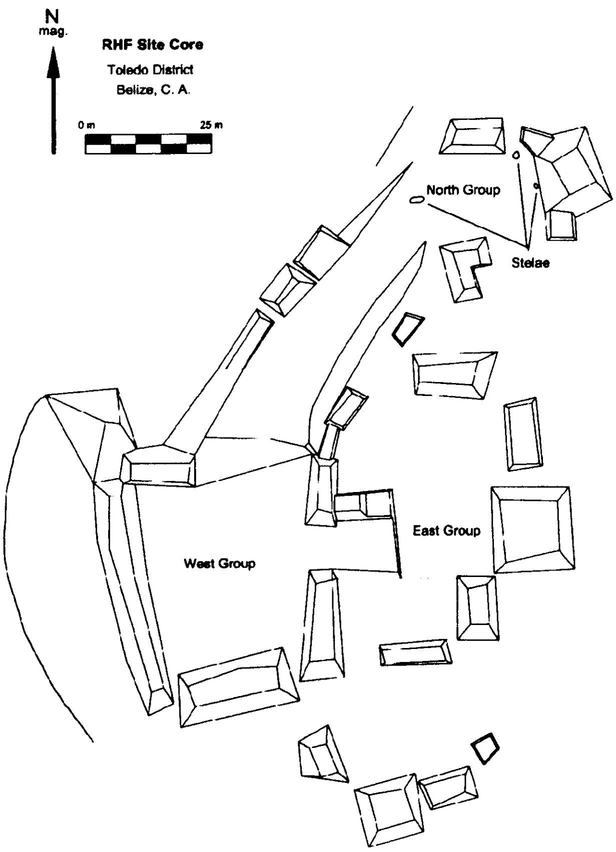

Figure 6: The RHF Site Core (map by M. Abramiuk, based on MMAP survey map).

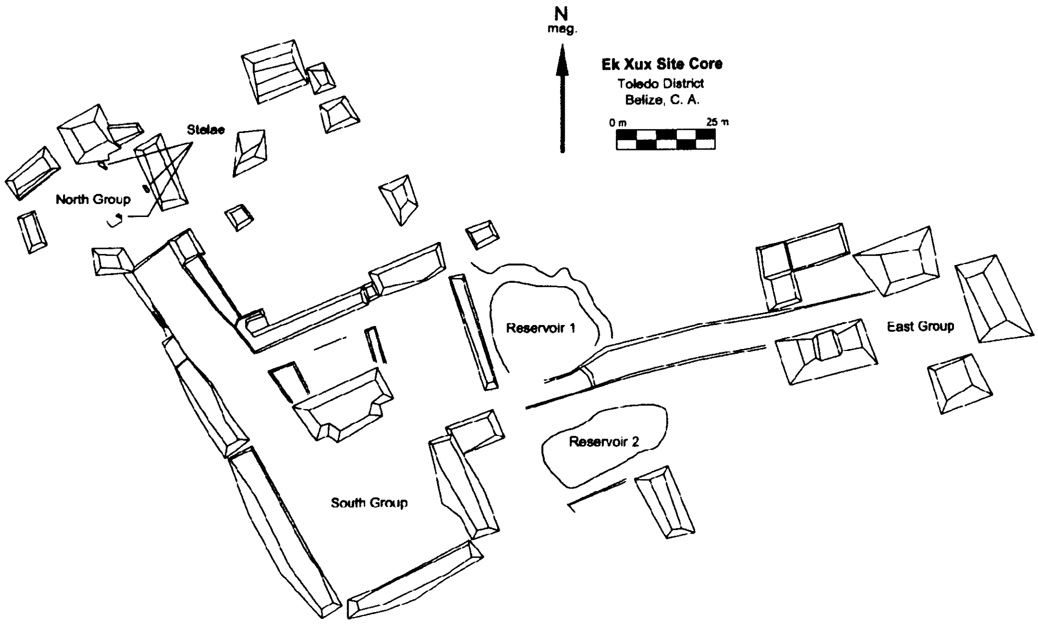

Figure 7: The Ek Xux site core (map by M. Abramiuk, based on MMAP survey map).

communities were part of a larger regional polity.

Politically, very little is known about the Bladen sites. What is known of these sites must be inferred from texts from the nearest significant polities, namely Nim Li Punit, Xnaheb, Uxbenka, Lubaantun, and Pusilha, located in the southern foothills of the Maya Mountains (Wanyerka 1996, 1999). The texts from these sites suggest that there was an Early Classic Tikal presence with what appears to be a close relationship with Copan during the Late Classic (Phil Wanyerka, personal communication 2003).

Whatever the details of the political hierarchy in the region, the Bladen communities seem to have been integral in exploiting rock and mineral resources which were in demand. As a result, the Bladen region would have empowered economically any polity that held a political claim to the area. The extent of the demand for the resources of the Bladen region is one of the points that this chapter will address.

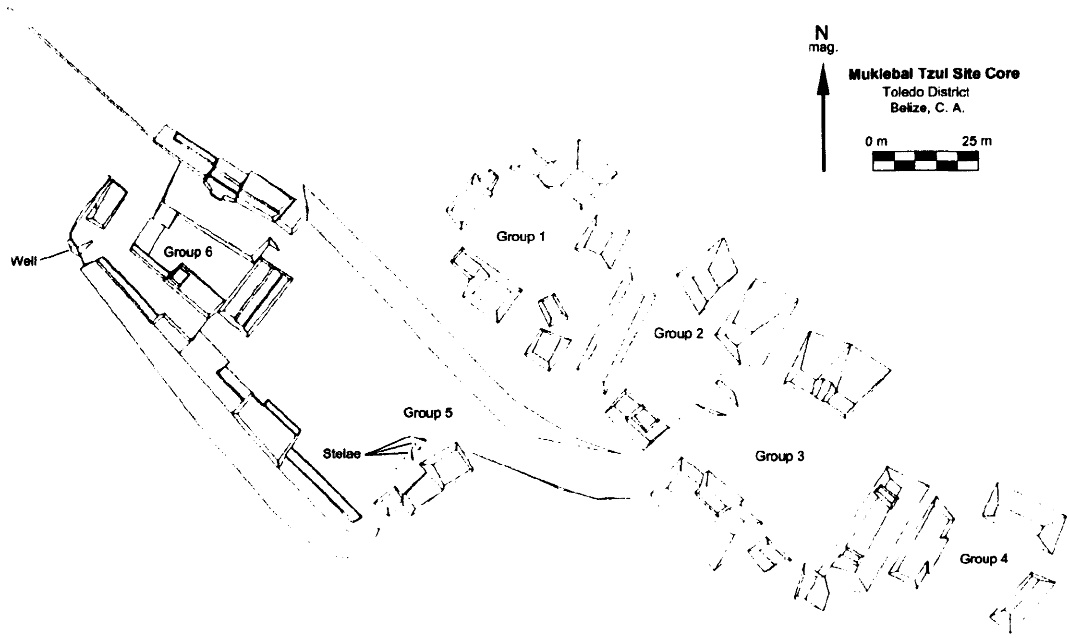

Figure 8: The Muklebal Tzul site core (map after Kindon [2002]).

5.3 Summary of the Geology of the Bladen Branch Region

The Maya Mountains are the only significant area of topographical relief in the Maya lowlands (Dixon 1956). Whereas the Yucatan peninsula is predominantly limestone, the Maya Mountains are considered to be an uplifted fault block composed of Late Paleozoic sedimentary and volcanic rocks, which make up the Santa Rosa Group (Bateson and Hall 1977; Cole and Andrew-Jones 1978). The volcanics, which are known as the Bladen Volcanic Member of the Santa Rosa Group, are localized around the Bladen Branch of the Monkey River (Druecker 1976, 1978). Also within the Santa Rosa Group are several large and small granitic intrusions. The three major areas of granitic rocks are the Cockscomb Sapote batholith, the Mountain Pine Ridge batholith, and the Hummingbird batholith (Shipley 1978). My focus will be on the lithologic variations along the Bladen Branch, particularly those lithologies that were used for manufacturing manos and metates.

The southern Maya Mountains are bounded by three east-west running faults: the Chiquibul and Sapote faults on the north and the Bladen fault on the south. The Bladen Volcanic Member, consisting of volcanic sediments, lavas, and tuffs, is exposed along the Bladen fault where the fault is in contact with Cretaceous limestones. The Cretaceous limestones onlapped the volcanic rocks from the south during the late Cretaceous and early Tertiary periods (Rao and Ramanathan 1990; Ramanathan and Garcia 1991) and comprise the karstic terrain south of the main course of the Bladen River. Most of this limestone is massive but it is finely bedded near the Bladen's headwaters. The Bladen volcanics, located in the southwestern portion of the Maya Mountains, are a volcanic mass 50 kilometers long on the east-west axis and 3 to 12 kilometers wide on the north-south axis (Druecker 1976).

Bateson and Hall (1971, 1977:1,3) were the first to find structural evidence that supported Sapper (1889) and Ower's (1928) claims that the Palaeozoic sediments were in fact one continuous series (Druecker 1976:3). Bateson and Hall (1971, 1977:1,3) also suggested that Dixon's porphyry occurred during the deposition of the Palaeozoic sediments and not later. Bateson and Hall recommended that the complex pile of lavas, ash-flow tuffs, breccias, and volcanic sediments that compose the porphyry be called the Bladen Volcanic Member.

Hall and Bateson (1972) were the first to observe that the lavas that peel away from the center of the volcanic mass are interbedded with volcanic sediments and pyroclastics. These lavas are rhyolitic in composition, which suggests that they are extrusive flows. Petrologically, the lavas are alkali rhyolites that are fairly uniform throughout the region, although the texture and grain size varies greatly. The rhyolites vary in texture from felsite to coarsely porphyritic, with relatively large phenocrysts (Bateson and Hall 1977:9). According to stratigraphic evidence, the volcanism that produced the Bladen Volcanic Member is believed to have taken place at the Permo-Carboniferous boundary. The date is confirmed by a radiometric dating of 300×10^6 b.p. (Bateson and Hall 1971:530).

Although research in the area (Hall and Bateson 1972; Bateson and Hall 1977:9) suggests that the Bladen Volcanic Member comprises mainly rhyolitic lavas and tuffs, Druecker (1976:7) has found that the Bladen volcanics support a more variable composition. Druecker notes that many of the ash-flow tuffs are quartz latites or latites with much of the quartz in silicified matrix and veins. The porphyritic lava flows, on the other hand, though they tend to be rhyolitic in composition, can also be classified as quartz latites. These rocks vary primarily in their feldspar composition.

Druecker (1976:9-10) observed that there were two main episodes of metamorphism and folding. The first episode was a regional metamorphism, which occurred contemporaneously with or after a folding event in the Palaeozoic sediments and volcanics. The second metamorphic episode was a much more intense dynamic shearing. The areas that were most affected by this event were ash-fall tuffs and volcanic sediments of the Bladen Volcanic Member (Druecker 1976:9).

The Santa Rosa group in the Bladen area is sericitized and silicified (Druecker 1976:10). Sericite development in the region was related to both metamorphic events. While the lava flows are only moderately sericitized, the tuffs are highly sericitized in the matrix and crystal fragments. Silicification of the Bladen volcanics occurred long after the metamorphic events and is related to hydrothermal activity. Druecker (1976:10-12) suggests that there are two episodes of quartz veining. The first is associated with a massive non-mineralized bull quartz, and the latter is associated with sulfide mineralization. As a result of this last episode, pyrite is ubiquitous throughout the Bladen area in the form of small crystals. These pyrite cubes are densest within the tuffs and volcanic sediments, which have high permeability.

The hydrology of the Bladen is complex. In some places, Bladen Branch flows along a fault trace (Dixon 1956:45-46) from west to east. However, in most places the Bladen flows from north to south underground along the same courses that Bladen's northern tributaries are flowing (Tom Miller 1996, personal communication).[1] The acidic groundwater derived from the erosion of the silicic rocks has deeply incised the limestone creating sinks and steep-walled tributary valleys. It is within these tributary valleys that Classic Maya sites, which I will be considering, are situated (refer to Figure 5). Since the rugged topography, thick vegetation, and limestone cover make systematic mapping of the volcanic sequence problematic, outcrop mapping combined with examination of floats was used to define the variability of lithologies along the Bladen Member (Dunham *et al* 1994-1998).

5.3.1 Distribution of Lithologies Along the Bladen

The distribution of lithologies will be described along the strike of the Bladen, from east to west, with respect to the northern tributary valleys and traditional logging campsites, the names of which are now used to describe the area in which the camps were located (Abramiuk and Meurer, *ms.*).

[1] Tom Miller is a hydrologist/speleologist who has done extensive research throughout Belize, particularly in the Maya Mountains, and has been affiliated with the Maya Mountains Archaeological Project (MMAP) since 1994.

Forest Hill Camp to Richardson Creek

The lithologies from Forest Hill camp west to Richardson Creek consist primarily of volcanic ash deposits that are only partially silicified. Hypabyssal rocks comprise approximately 10 percent of the material examined and these include samples with large (2 cm) euhedral K-feldspar phenocrysts in a fine dark matrix (Abramiuk and Meurer, *ms.*).

Quebrada de Oro, Teakettle Camp, and Ramos Quebrada

The rocks of Quebrada de Oro, Teakettle camp, and Ramos Quebrada are a combination of volcanic ash deposits and volcaniclastic rocks. The volcanic ash deposits of this area are similar in appearance and degree of silicification to ash examined from the Forest Hill/Richardson Creek area. The volcaniclastic rocks are composed of detrital fragments that include sedimentary rocks (mudstones and sandstones), volcanic rocks (mostly chunks of welded tuff), and pieces of massive hydrothermal quartz, in a matrix that appears to have formed by erosion of unconsolidated ash deposits. The sedimentary rocks range from medium-grained sandstones to conglomerates with clasts up to 2.5 cm in diameter (Abramiuk and Meurer, *ms.*).

Ek Xux and Cuyamel Valleys

The Ek Xux and Cuyamel pockets contains volcanics and hypabyssal rocks that are aphyric and extremely silicified. The volcanics consist of silicified volcanic ash, ranging from aphyric to 20 volume-percent crystals of quartz and feldspar and welded tuff. Several samples contained one to three percent sulfides, predominately pyrite. The hypabyssal samples contain euhedral K-feldspar, pseudotetragonal quartz crystals, and three percent sulfides, possibly pyrohytite. Volcaniclastics do not occur in the area (Abramiuk and

Meurer, *ms.*).

Muklebal Valley

The Muklebal valley differs from the tributary valleys of the rest of the Bladen in that it consists predominantly of finely bedded shallow water limestones with local occurrences of chert nodules and hydrothermal quartz veins. This is probably due to the fact that water has not cut through the limestone covering the Volcanic Member. The finely bedded limestone breaks readily along bedding surfaces producing regular blocks that were used in construction of the Muklebal Tzul site, giving it a distinctive appearance from the rest of the sites along the Bladen Drainage. Mudstone, temporally related to the limestone and not part of the Santa Rosa Formation, was also found in some stream cuts but it weathers extremely readily and is not found outside of streams. Volcanic and volcaniclastic rocks are scarce or absent in the area (Abramiuk and Meurer, *ms.*).

5.4 Method of Sourcing

Three steps were involved in the procedure for sourcing ground stone artifacts. The first step consisted of sampling the cultural material (manos and metates). The second step involved interpreting the geology of the Bladen region on the basis of the source material (rocks) collected by the MMAP. And the third step consisted of comparing the source material with the cultural material.

5.4.1 Sampling of Cultural Material

Samples of artifacts were collected from the Bladen sites as well as from lowland sites outside of the Maya Mountains to determine whether the ancient inhabitants utilized resources from the Bladen region.[2] Ground stone implements, particularly manos and metates, are the kinds of artifacts that were sampled for this analysis.

All of the ground stone artifacts at Ek Xux and Muklebal Tzul that were sampled for this study were taken from the 1996-1999 MMAP excavations (Dunham *et al* 1996-1999). These excavations primarily targeted residential complexes at the sites. The ground stone artifacts that were sampled from Ek Xux and Muklebal Tzul can be dated to the latter part of the Late Classic and Terminal Classic, since they were found in context with carbon samples and diagnostic ceramics which date to this period (Kindon 2002:269).

Due to permit restrictions from the Department of Archaeology and the Department of Forestry no excavations were permitted at the Quebrada de Oro Ruin and the RHF Site. As a result, the artifacts at the Quebrada de Oro Ruin and the RHF Site had to be sampled using a different method which is commonly used in the Maya area. Surface collection from random housemounds in and around the site cores was the means by which ground stone samples were obtained from these sites. Surface collections do not convey the temporal resolution that excavations do, but knowing that these communities were coeval and relatively short-lived, as I discussed above, is sufficient to permit me to construct a working model of inter-community exchange.

Samples of artifacts from sites in other parts of the Maya Lowlands were

[2]The Maya Mountains, even though technically they can be regarded as highlands, are part of the Maya lowlands.

taken from the collections of the Department of Archaeology in Belmopan (DOA). Details regarding the excavation history of the artifacts that were sampled can be obtained from the DOA. The DOA identification numbers that are used for the ground stone artifacts have been provided in Tables 8.5-8.5.

In all cases, only broken artifacts were sampled. When an artifact was located, its provenience was noted, it was drawn, and then it was photographed. A hammer and chisel were used to remove the sample from the artifact.

5.4.2 Geological Interpretation of the Bladen Region Based on the Source Material

Most of the source material that was used in this analysis was collected between 1993 and 1998 by the MMAP. Due to the dense foliage, the primary means of acquiring samples was through collecting floats from the streambeds of the Bladen Branch and its tributaries.

The distribution of rock types along the length of the Bladen River (see *Appendix A*) is consistent with the exposures of two volcanic centers. Shallow intrusive or hypabyssal rocks are most abundant near Richardson creek and Ek Xux, which suggests that these are the locations of the two volcanic centers. The spacing between these centers is the same as the average spacing of volcanoes along numerous arcs (i.e. roughly 20 km) (Wilson 1989). The Quebrada de Oro area, which is approximately halfway between Richardson Creek and Ek Xux, has lithologies that are dominated by volcanic ash and volcaniclastic (sedimentary) rocks. The ash deposits in the Quebrada de Oro area are distal ash falls from these volcanic centers and the volcaniclastic rocks are being shed off of the volcanic edifices by erosion. The presence of more intrusive rocks to the east (near Richardson Creek) may indicate a slight tilting of the arc toward the west so deeper erosional levels occur toward the east (William Meurer, personal communication 2002).

The Maya Mountains along the Bladen Branch are a highly segmented distribution of rock types which lie along the length of the east-west trend of the Bladen. The local weathering processes, which have resulted in the north-south tributaries, have cut deep into the volcanic rocks thereby exposing rocks all along the volcanic arc (i.e. east-west trend of the Bladen Branch). Because the two main volcanic centers occur at either end of the Bladen Branch and the north-south valleys lie along the strike of the former volcanic arc, none of the intrusive volcanic rocks found near Richardson Creek or in the Ek Xux area are found in Ramos Quebrada or Quebrada de Oro. Similarly, the volcaniclastic rocks so common in these two drainages are absent both up and down stream.

5.4.3 The Source Material and its Political Economic Implications for the Communities

Macroscopically, volcanic rocks, volcaniclastic rocks, mudstones, and siltstones are all distinguishable from one another, and since these materials occur in specific valleys, it was relatively straightforward to determine where artifacts made from these materials originated. As a result manos and metates in the Bladen region would have constituted what may be termed *communal goods*, or goods that have distinct characteristics that can be attributed to specific communities situated in their associated valleys, as discussed above in Section 4.2.2.

The volcanics from Ek Xux and those from Forest Hill differ slightly in their silicification and so can be distinguished from each other, albeit with less confidence. The volcaniclastic materials from Ramos Quebrada and Quebrada de Oro are indistinguishable macroscopically, and other measures will be taken in the future to distinguish between the two kinds of volcaniclastic materials.

This geological evaluation has important political economic implications for the Bladen communities. Three of the four communities were located in valleys with highly distinct lithologies. The rock resources from two valleys — namely Quebrada de Oro in which the Quebrada de Oro Ruin is situated and Ramos Quebrada in which the RHF Site is located — are indistinguishable. If we propose the idea that these sites were founded in order to exploit specific resource (rock) types, as Dunham *et al* (1995, 1996) suggest, then the Quebrada de Oro Ruin and the RHF Site were probably exploiting an entire resource zone as a single economic and possibly political entity.

There are some observations that give credence to this notion. Politically autonomous communities are frequently distinguished by the presence of stelae. At Quebrada de Oro we have a ballcourt which is also an important feature at many autonomous sites, but no stelae, and at the RHF Site we have a stela plaza, but no ballcourt. The presence of stelae, central to the notion of an autonomous community, suggests that perhaps these two sites functioned as one unit, politically as well as economically. The notion of twin polities has been well documented in the Maya lowlands (Houston 1993; Sharer 1994:220-225; Martin and Grube 2000:61-62).

Because the Quebrada de Oro Ruin and the RHF Site could be regarded as a single political economic entity, only three sites or urban centers will be considered and they will be identified by the modern site names of: Muklebal Tzul, Ek Xux, both of which are situated in the upper Bladen, and the Lower Bladen sites (i.e. a combination of the Quebrada de Oro Ruin and the RHF

Site).[3]

5.4.4 Results of the Comparative Analysis Along the Bladen

After assessment of the relationship between the source material and the geology of the Bladen region, the artifacts from the Bladen sites and the non-Bladen sites were compared with the source rock samples from the Bladen. Hand-sample comparison, demonstrated in *Appendix B*, was augmented by examinations of the thin-sections of the artifacts.

A procedure was devised so that the results of the hand-sample comparisons could be reproduced in future analyses of the data. This procedure involved a system of five straightforward rules that assigns a rank of confidence for comparing source and cultural material. The confidence-ranking scheme was based on a ranking system from 0 to 10. In this system:

- 10 indicated that a *perfect* match for the artifact was found in the source rock collection for a specific valley, with no close matches in the other valleys;
- 8 indicated that a *perfect* match for the artifact was found in the source rock collection for a specific valley;
- 6 indicated that a *close* match for the artifact was found in the source rock collection for a specific valley, with no other close matches in the other valleys;

[3]Throughout the remainder of this thesis, the term "Lower Bladen sites" will refer to both the Quebrada de Oro Ruin and the RHF Site.

- 4 indicated that a *close* match for the artifact was found in the source rock collection for a specific valley;
- 2 indicated that no close matches for an artifact in the source rock collection were found, but that based on the geology of the Bladen Branch, a specific source for the artifact could be inferred; and
- 0 indicated that no specific source for the artifact was known.

In addition to these designations of confidence, one assumption was made regarding the sourcing of manos and metates. If a mano or metate was made from a rock type that occurred in more than one tributary valley of the Bladen, then the closest of the valleys to the spot where the mano or metate was found was considered to be the source. This assumption is based on Zipf's (1949) least effort principle and is justified for many human activities (Trigger 1990). This assumption is also supported in the archaeological record for the Classic Maya. For example, most bulky ceramics and utilitarian wares can be sourced to local workshops rather than distant workshops at Tikal (Fry 2003:150-151), and this is generally considered to be true of lithics in northeastern Belize as well (Kelly 1982:96).

To illustrate how this assumption was used in the sourcing of manos and metates in the Bladen region I provide an example. Mudstone and siltstone occur naturally in the Quebrada de Oro, the Ramos Quebrada, and the Muklebal valley. Using the assumption stipulated, a mudstone or siltstone artifact found in any of these valleys is considered to be manufactured locally, and a mudstone or siltstone artifact at Ek Xux is considered to come from the nearby Muklebal valley. Similarly, moderately silicified volcanic rocks occur naturally in the Quebrada de Oro, the Ramos Quebrada, and the Ek Xux valley. Thus, following the assumption stipulated, a moderately silicified

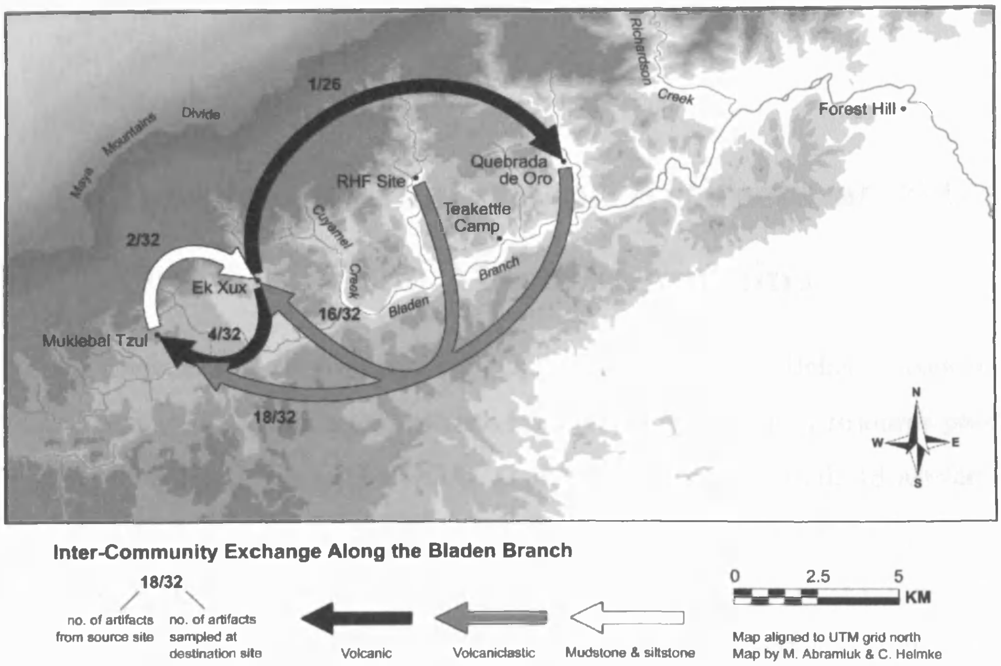

Figure 9: The Bladen Branch exchange system.

volcanic artifact found in any of these valleys is considered to be manufactured locally, and a moderately silicified volcanic artifact at Muklebal Tzul is considered to come from the nearby Ek Xux valley.

Also of special note is the fact that one out of twenty-six artifacts sampled at the RHF Site, one out of thirty-two artifacts sampled at Ek Xux, and three out of thirty-two artifacts sampled at Muklebal Tzul were made from vesicular basalt, and could only have come from the Maya highlands. One artifact out of thirty-two artifacts sampled at Ek Xux was a metamorphic variety that is not seen in the Maya Mountains, and likely came from one of the metamorphic sources in the highlands of western Guatemala or northern Honduras (West 1964:67).

Appendix C contains the results of the hand-sample comparisons with associated confidence levels, and Figure 9 synthesizes these results and represents the movement of ground stone along the Bladen Branch using arrows.

5.5 Results of Analysis of Artifacts at Sites Outside of the Maya Mountains

At the Department of Archaeology (DOA) in Belmopan, Belize, I concentrated on sampling mano and metate fragments from sites in resource poor regions of Belize.[4] From the DOA, 17 artifacts from Nohmul, 18 artifacts from Lubaantun, 3 artifacts from Sarteneja, 1 artifact from Hat Cay, 1 artifact from Billy Barquedier Creek, 5 artifacts from Little Rocky Point, 32 artifacts from Altun Ha, 23 artifacts from Baking Pot, 3 artifacts from Caledonia, and 11 artifacts from Xunantunich were analyzed.

All of the artifacts at Nohmul were limestone except for one artifact, which was granite. All of the artifacts from Lubaantun, Sarteneja, Hat Cay, Billy Barquedier Creek were vesicular basalt as were two of the samples taken from Little Rocky Point, evidence that vesicular basalt was moving northeast along the southern coast of the Yucatan from the Maya highlands. The sheer abundance of vesicular basalt artifacts, specifically at Lubaantun, suggests that Lubaantun or one of its neighbors may have functioned as a central distributor of this material to the other communities in southern Belize (e.g. the Bladen communities). The other two artifacts sampled from Little Rocky

[4]Some sites were sampled which were near to regions with hard rock to manufacture manos and metates, but this sampling was unintentional. The focus of my research was to head to southern Belize to sample ground stone from the Bladen sites and from the MMAP storage barracks which contained ground stone from previous excavations at Ek Xux and Muklebal Tzul. No more than 20 artifacts from sites in poor resource regions outside of the Bladen were supposed to be sampled at the DOA. However, forestry and archaeology permits were delayed, stranding me in Belmopan longer than I would have hoped. I, therefore, used this time constructively to sample more artifacts from sites I had already sampled at the DOA (e.g. Altun Ha), as well as other sites which I previously had no intention of sampling because they were near hard rock resources (e.g. Caledonia).

Point were granite, whereas one was limestone. The granites came from one of the three granite batholiths in Belize (Shipley and Graham 1987; Graham 1987) based on macroscopic examination.

5.5.1 Figure 3: Sites with Connections to the Bladen Communities

My analysis of the artifacts found at sites outside the Bladen (Figure 3) suggests that manos and metates were being exported from the Bladen region (see *Appendix D*). It is even possible to pinpoint specific Bladen communities that were responsible for exporting the goods. Volcaniclastic artifacts confidently can be said to have come from either the Quebrada de Oro or the Ramos Quebrada. This would make either the Quebrada de Oro Site and/ or the RHF Site, respectively, the agents of export for the volcaniclastic goods. It can also be said with confidence that volcanic artifacts at sites outside of the Bladen region came from the Ek Xux valley, making Ek Xux the likely agent of export of volcanic goods. The reasoning behind this is based on the assumption that the inhabitants of the Bladen communities were taking advantage of what their valleys had to offer. While it is not certain whether this kind of entrepreneurship functioned at a local level, it seems very likely that it would have been operational in the Bladen region's interaction with the rest of the Maya world. Specialization in manufacturing goods made from distinct rock types would have been important for the Bladen communities that wanted to occupy niches in Maya economy. For the Quebrada de Oro Site and the RHF Site this would have meant taking advantage of the volcaniclastic rocks, and for Ek Xux, this would have meant taking advantage of the various silicified volcanic rocks.

Thirteen of the samples taken from Altun Ha were granites. Four artifacts at Altun Ha, however, came from the Bladen. Three were volcaniclastic indicating a connection to either Quebrada de Oro or RHF, and one was volcanic indicating a connection with Ek Xux. All of the Altun Ha samples come from Terminal Classic contexts or later except for one of the volcaniclastic samples, which comes from the seventh century A.D. (David Pendergast, personal communication 2003; Pendergast 1979, 1982). This indicates that ground stone was being exported from the lower Bladen communities from the Late Classic to Terminal Classic, and that Ek Xux was exporting its material in the Terminal Classic.

Of the twenty-three samples taken at Baking Pot, seventeen were granite, but four items were made from Bladen material. Even though recent work at Baking Pot has produced evidence of much earlier phases, the artifacts that were sampled are from the Late Classic period (see Bullard and Bullard 1965). Three of the artifacts from Baking Pot were volcaniclastic, and one was volcanic; appearances of both types of artifacts are representative of contact with both the lower and upper Bladen sites, respectively. This indicates that both Ek Xux and the lower Bladen communities were actively engaged in exploitation and exportation during the Late Classic.

Finally, one artifact out of the three sampled at Caledonia is volcanic and, therefore, probably comes from Ek Xux, whereas one artifact out of the eleven sampled from Xunantunich is volcaniclastic of the variety witnessed in the Bladen, and likely came from either Quebrada de Oro Ruins or from the RHF Site.

In addition to the artifacts inspected at the Department of Archaeology in Belize, the thin-sections from Shipley and Graham's (1987) ground stone study at Seibal were analyzed. Out of the 13 artifacts sampled at Seibal by Graham, three were confirmed to have originated in the Bladen. One is volcaniclastic implying a connection with either the Quebrada de Oro Ruins or the RHF Site and the other two artifacts are volcanic implying a connection with Ek Xux. All but one of the volcanic artifacts dates to the Terminal Classic (Willey 1978).

Figure 10 synthesizes the results of the provenance analysis conducted on the sites which were importing Bladen ground stone material.

		Destinations				
		Altun Ha	Baking Pot	Caledonia	Seibal	Xunantunich
Sources	Quebrada de Oro/ RHF	3	3	0	1	1
	Ek Xux	1	1	1	2	0
	Muklebal	0	0	0	0	0
	TOTAL	32	23	3	13	11

Figure 10: Number of artifacts from sites outside of the Bladen region which can be sourced to the Bladen communities. The bottom row displays the total number of artifacts that were sampled at the sites outside of the Bladen.

5.6 Interpreting the Petrographic Results

Only two artifacts at the RHF Site were volcanic and only one was made from siltstone. The rest of the artifacts at the RHF Site were volcaniclastic. Only five artifacts at the Quebrada de Oro Ruins were volcanic and two artifacts were mudstone. The rest of the artifacts were volcaniclastic. These last two observations suggest that *locally*, grinding implements made from volcaniclastic material were preferred. This is further supported by the fact that great quantities of volcaniclastics were imported into Ek Xux and Muklebal Tzul, implying that volcaniclastic material was in great demand throughout the Bladen. Volcanic material was the second most preferred material in the Bladen and this is supported not only by the fact that volcanics were the second most abundant material at Quebrada de Oro Ruins and the RHF Site, but by the fact that Ek Xux imported less materials than did Muklebal Tzul, a community which is situated in a valley with no volcanics.

Adopting a wider view, it appears that volcanics were in demand throughout the Maya realm, just as the volcaniclastics were, if we consider the findings at Altun Ha, Baking Pot, Caledonia, Xunantunich, and Seibal. Mudstone, on the other hand, appears to have been in little demand locally, since we see so little of it at the Bladen sites, except at Muklebal Tzul. The abundance of mudstone artifacts at Muklebal Tzul is, no doubt, explained by the fact that mudstone was the only local material with properties comparable to but not nearly as preferred as the volcaniclastic material. Thus far, no mudstone artifacts have been observed at sites outside of the Maya Mountains.

The demand was high for volcanics and volcaniclastics outside of the Maya Mountains, but what the exchange relations were that stimulated export is at this time unknown. Commerce is one possibility, but tribute requirements may also have been a stimulus.

5.7 Discussion of Exchange Behavior

Up to now, exchange has been accepted *a priori* as the behavior responsible for the distribution of ground stone at the Bladen communities. However, large-scale migrations of people with their belongings have been known to occur in the Maya area. For example, it is this explanation that Hammond (1975:102-103) gives for the rise of Lubaantun. Therefore, could it be that migrations of people with their possessions, moving from the lower Bladen (the Quebrada de Oro Site and the RHF Site) to the Upper Bladen (Ek Xux and Muklebal Tzul), were responsible for the manner in which ground stone was distributed along the Bladen? The answer to this question is that it is unlikely, and the reason for this will be discussed next.

The reason why this topic was not broached before is that the idea that exchange is the prime behavior behind the movement of ground stone has to be inferred from the sourcing results. It was, therefore, necessary to discuss the results of the sourcing before a thorough discussion of the behavior behind the movement of ground stone could take place.

1. To support the argument for exchange along the Bladen, I will begin with the fact that significant quantities of materials were being exported from the Bladen region to lowland sites outside of the Maya Mountains. That is, the proportion of the ground stone used at Altun Ha, Baking Pot, Caledonia, Seibal, and Xunantunich that came from the Bladen communities during the Late and Terminal Classic is significant, as Figure 10 can attest to. The sheer abundance of artifacts from the Bladen at communities outside of the Maya Mountains from the Late and Terminal Classic periods suggests that there was ground stone being exported from the Bladen communities throughout these periods.

2. The second fact is that if people were migrating from the lower Bladen to the upper Bladen, not only would there be a population increase in the upper Bladen, but there would be a corresponding population

decrease in the lower Bladen, and we do not see evidence for this happening along the Bladen Branch. Though Ek Xux was probably gaining people during the Late Classic (Abramiuk 1998), there is no evidence to suggest that the lower Bladen communities were simultaneously losing their populations. This latter point is supported by the third fact, which will be discussed next.

3. The third fact is that significant populations were needed for procuring the raw materials, for manufacturing manos and metates, and for administrating production and export of the goods. In order to produce the continuous level of economic output that is witnessed in the archaeological record throughout the Late and Terminal Classic, it follows that there always needed to be significant populations at the communities. Large-scale migrations from the lower Bladen to the upper Bladen would have been unlikely since the Bladen communities were operating concurrently, and the repercussions of a large-scale abandonment of one of the communities and migration to one of the other Bladen communities would have certainly been detected in the quantities of ground stone produced for sites outside of the Maya Mountains. Instead there seems to be a relatively continuous flow of ground stone from both the upper and the lower Bladen communities throughout the Late and Terminal Classic, according to the analysis of the Bladen artifacts at Altun Ha, Baking Pot, and Seibal.

I conclude that while some of the movement of ground stone between the Bladen communities might be the result of small-scale migrations, the movement of most of the ground stone is not the result of large-scale migrations. This is because significant amounts of ground stone were being exported out of the upper and lower Bladen communities simultaneously and continuously throughout the Late and Terminal Classic periods. For this to have occurred, large sedentary populations were needed at the communities in order to procure, manufacture, and facilitate the export of the ground stone. Without these sedentary populations we would not have observed what appears to be a continuous output of ground stone from the upper and the lower Bladen communities at the sites of Altun Ha, Baking Pot, and Seibal. Because both the upper and lower Bladen sites were thriving, there would appear to be no reason for large-scale migrations.

Since it is unlikely that large-scale migrations were behind the movement of the ground stone along the Bladen, the movement of such significant quantities of ground stone along the Bladen was probably the result of exchange.

If we take the ethnohistoric data on the Quiche Maya discussed in Section 4.2 and the archaeological data from the Bladen as an indication of the mode of exchange that existed along the Bladen, then direct reciprocity or market exchange was likely responsible for the movement of ground stone along the Bladen. Unfortunately, the distribution of ground stone along the Bladen cannot expand on the ethnohistoric evidence due to the proximity of the communities. Not only is Renfrew's (1975:41-43) research on associating particular distribution patterns to the modes of exchange more applicable for long-distance exchange, but more work with regard to its application even for long-distance exchange needs to be undertaken (Torrence 1986:115-121).

If the market system in the Guatemalan highlands today is any indication of the way markets were run in Classic Maya times, then each community would have had its own market day during the week, and this cyclical market system would have funneled goods from all of the communities involved in the cyclical exchange system to the one community having the market. This would have potentially provided consumers at each of the communities access to all kinds of goods directly within the consumer's community, and this would have had the effect of evenly distributing goods, provided all buyer preferences were the same in each of the communities.

In other words, gaining access to specific ground stone implements would not have had significant effect on the distribution of ground stone at the sites because if someone needed something from another community, the consumer could either access it by waiting for the market to come to the consumer's community, by walking to a nearby community where there was a market, or by exchanging with someone from a different village outside of the market system (i.e. direct reciprocity). Differences in the distribution of ground stone at each of the sites, therefore, were probably due to how much the consumer needed or wanted a particular good. Because all four Bladen communities are well within walking distance of each other, they would have had relatively equal access to ground stone implements at markets or through direct reciprocity. It seems likely that the distribution of ground stone would have been more of an indication of compositional preference, rather than mode of exchange.

Nevertheless, I find that one point probably can be made with regard to exchange types, which is that the mode of exchange known as direct access (Renfrew 1975:41) seems to be an unlikely means in which ground stone was distributed along the Bladen. Direct access, in the case of the Bladen communities, would imply that someone from a community in one valley could go to another valley and access its resources "without reference" to the people of the community in the other valley. However, in the Bladen area, "reference to" the people of the communities in the valleys was probably unavoidable, especially since settlement took up so much of the valley floors and indications are that population densities were probably very high

(Abramiuk 1998). The Bladen communities were also situated in such a way that they likely exploited their own procurement zones (Dunham *et al* 1995, 1996) and consequently may have restricted outsiders' access to the resources of their valleys. This territorial behavior would also explain why the Bladen communities, at least in terms of settlement features, give the appearance of being Classic Maya polities, albeit small polities.

5.8 Exchange Behavior Along the Bladen: Function and Beyond

5.8.1 Functional and Non-Functional Behavior Among the Bladen Maya

From our comparative analysis, it is assumed that exchange was motivated primarily by functional factors. Certain rock types seem to have been preferred for their functional properties in the Bladen region and, it would seem, the rest of the Maya lowlands. The difference in the proportions of compositionally distinct grinding implements at the sites suggests that the rock type that was preferred was volcaniclastic. This makes sense, since it is the only rock type out of those that were used in the Bladen that is soft enough to shape into manos and metates but resilient enough not to chip while grinding grains and seeds. In other words, it is considerably harder than mudstone, but more malleable than volcanic rock. After volcaniclastic rock, volcanic rock seems the most preferred material for making grinding implements, followed by mudstone, which is the least used material for manufacturing grinding implements.

In addition to functional behavior, non-functional behavior has also been detected in the comparative analysis, and it is this anomalous behavior witnessed in the archaeological record that is especially noteworthy. For example, mudstone, an extremely soft ("poor quality") stone for making manos and metates, and one that would grind down quickly during food processing, was found at Ek Xux, where more resilient ("better quality") volcanic rocks were abundant. Similar non-functional behavior seemed to have operated at the Quebrada de Oro Ruins, which had easy access to volcaniclastic material and where a highly silicified volcanic ground stone fragment from the Ek Xux valley was found. In these sorts of transactions it would appear that exchange was not always motivated by the need to obtain good quality grinding stones. In this regard, the operative mechanisms behind ground stone exchange in the Bladen region were distinctly different from the operative mechanisms which were motivating long-distance trade.

5.8.2 Differentiating Bladen Maya Exchange Behavior from Inter-Regional Maya Exchange Behavior

The economic relationships between the Bladen communities and the lowland communities outside of the Bladen region were different from the economic relationships among the communities in the Bladen region. Within the Bladen the flow of grinding implements between communities was *bidirectional*, whereas the flow of grinding implements between the Bladen communities and the communities outside of the Bladen was *unidirectional* (i.e. from the Bladen region to the surrounding lowland areas).

Grinding implements that were exchanged among the Bladen communities seem to have been exchanged for a *symbolic* reason; that is, there was something about the manner in which manos and metates were perceived in the Bladen which differed from the way manos and metates were perceived outside of the Bladen. This contrast is apparent in the marked difference in directionality in the two exchange systems, if we assume that one's conception of an object type, such as grinding implements, determines the movement of that object type across the landscape. As a result, it can be concluded that the economic systems constituting inter-community exchange within the Bladen, and inter-regional exchange between the Bladen communities and communities outside of the Bladen were qualitatively different systems. The difference between these economic systems reflects difference in the *meaning* that manos and metates held for Maya within the Bladen region as compared to the context of long-distance exchange.

A similar phenomenon was observed among the eastern Papua-Melanesians participating in Kula exchange (Malinowski 1984). The Kula exchange system entailed that bracelets be exchanged for necklaces, the bracelets and necklaces acquiring their symbolic significance only within the context of Kula exchange. The Kula exchange system, however, was distinct from the economic system that introduced the bracelets and necklaces into the Kula exchange system (i.e. the production sites). It was also distinct from the economic systems into which Kula items sometimes entered (i.e. the offshoot sites).

Malinowski explains how bracelets (or armshells) called *mwali* enter the Kula exchange system:

> "In the olden days, Murua probably was quite as productive a centre of this manufacture as the Trobriands , and in these latter though Kayleula and the Western islands fish and work the *mwali* as much as ever, the natives of Kavataria are almost entirely out of it, busy all the time diving for pearls. Both the main places of origin of the armshells, therefore, are [geographically] within

> the Kula ring. After they are made, or, as we saw in Kayleula, in the process of making, they enter circulation. Their entry into the ring [i.e. the Kula exchange system] is not accompanied by any special rite or custom, and indeed it does not differ from an ordinary act of exchange. If the man who found the shell and made the *mwali* were not in the Kula himself, as might happen in Kavataria or Kayleula, he would have a relative, a brother-in-law, or a head man to whom he would give it in the form of one or other of the many gifts and payments obligatory in this society" (Malinowski 1984:504-505; brackets mine).

Bracelets also fall out of circulation from the Kula exchange system and enter other economic systems. As a consequence, the rules for the exchange of the bracelets significantly differ in these other economic systems as Malinowski explains:

> "There is, however, one movement which specially interests us from the Kula point of view, namely that of the two types of Kula valuables. One of these articles, the armshells, travels on the South Coast from East to West. There is no doubt that this article leaks out from the Kula current at its Southernmost point, and is carried away towards Port Moresby, where the value of armshells is, and was, in olden days much higher than in the Eastern district. I found in Mailu that the local native traders purchased, for pigs, armshells in the Su'a'u district, and carried them West towards Aroma, Hula, and Kerepunu. Professor Seligman, from his notes taken at Port Moresby, informs us that Hula, Aroma, and Kerepunu import armshells into Port Moresby. Some

of these armshells, according to the same authority, travel further West as far as the Gulf of Papua" (Malinowski 1984:506).

As Malinowski makes clear, the differences in the economic systems and the resulting movement of objects can be attributed to a change in the exchange-values of the necklaces and bracelets. However, the inference that can be drawn from these passages is that bracelets and necklaces did not necessarily acquire different exchange-value so much as the rules of the exchange systems changed. For example, when leaving the Kula exchange system bracelets are exchanged for pigs rather than for necklaces. This implies a change in how the use-values of bracelets and necklaces compared. The Kula items did not serve the same symbolic purpose at the production sites and offshoot sites that they did among the Trobriand Islands where Kula exchange was practiced.

Differences in the symbolic significance of items and the rules which structure how the items are exchanged and distributed are critical for forming boundaries around economic systems. The contrasting directionality (bi- v. uni-) in the movement of grinding implements in the Maya area suggests that grinding implements which were exported to the large lowland communities were exported for functional, *pragmatic* reasons; that is, the Bladen communities were sending to the large lowland communities items made from materials that were not normally obtainable outside of the Maya Mountains (e.g. volcanics and volcaniclastics). This trade was directional and pragmatic because these large lowland communities outside of the Bladen region, which were importing grinding implements, reciprocated with other items (e.g. ceramics, jade and obsidian artifacts). They did not, for example, reciprocate with limestone manos and metates — which were also widely used among the ancient Maya (see *Appendix D*) and continue to be used among the contemporary Maya (Thompson 1939:174) — for we see no evidence of this occurring in the samples that were taken at the Bladen communities. If it is assumed that the meaning of an object — or how the use-value of the object compares with the use-value of another object — can be inferred from its movement across the landscape, the lack of reciprocity with the same object type has significant implications because it implies that that object type loses the precise meaning it held within the Bladen region. In other words, the meaning that an object has and which is shared between transactors is changed as it moves out of one context and into another. The object type relinquishes the meaning it had in the old context (i.e. within the Bladen region) and acquires a different meaning in the new context (i.e. between the Bladen region and the sites of Altun Ha, Baking Pot, Caledonia, Seibal and Xunantunich outside of the Bladen region). As a result of this transition to an inter-regional context, the entire character of the Bladen exchange process changes, this time operating according to different mechanisms which contrast with the mechanisms that governed grinding implement exchange within the Bladen region.

Functional economic exchange (i.e. I-lack-it-so-I-need-it exchange) is often assumed *a priori* in many archaeological case studies, but functional economics clearly do not fully explain the movement of grinding implements among the Bladen communities. In order to explain the movement of grinding implements I will look at what drove the demand for manos and metates in the first place. Only after this driving mechanism has been established will I turn to the production and exchange of manos and metates and the formal modeling thereof.

5.9 How Manos and Metates Were Utilized in the Bladen Region

To understand the mechanisms of exchange in the Bladen region, the symbolic manner in which manos and metates were conceived and utilized must be explained. One need not stray far from the ethnographic and archaeological evidence to ascertain the symbolic significance that manos and metates held for Maya in local contexts (i.e. among neighboring communities). The manner in which manos and metates were interpreted in local contexts is pertinent to the Bladen case study, since the Bladen communities comprised a local exchange system and the way in which manos and metates were interpreted "locally" by Maya people can facilitate our understanding of how the Bladen Maya interpreted manos and metates.

Manos and metates were not only essential for food processing but were utilized in rituals symbolizing termination and renewal. The number of manos and metates which would have been offered (taken out of circulation) during these rituals is relatively large when considering the sheer number of the dedicatory occasions in which the ancient Maya would have participated. These offerings of manos and metates occurred throughout the Maya area during the Classic period. Manos and metates have been found in termination offerings at Yaxuna (Freidel, Suhler, and Cobos Palma 1998:141) and Chichen Itza (Freidel 1998:190), in dedicatory rituals or in votive offerings at Cerros (Garber 1989; Garber *et al* 1998:128), and even in New Year celebrations (Garber 1989; Garber *et al* 1998:130). Taking manos and metates out of circulation on these occasions would have been essential for any Classic Maya household.

In addition to retaining a surplus of manos and metates for dedication and termination, a certain quantity of manos and metates had to be kept on hand for other ritual occasions such as deaths in the family, which frequently involved burial offerings of manos and metates — this is seen at Muklebal Tzul.

Therefore, it can be assumed that two needs pervaded the average Classic Maya household: the need to use and eventually discard manos and metates, and the need to save manos and metates. On one hand, households utilized grinding implements for domestic purposes (i.e. food processing) and spiritual purposes (i.e. offerings) and when these items served their purpose they were discarded. On the other hand, households retained a number of grinding implements for unpredictable circumstances, such as deaths in the family.

5.10 Conclusion: The Bladen Case Study

This chapter is concerned with the archaeological research I conducted in the Bladen region. The archaeological research required that both fieldwork and laboratory work be conducted. The fieldwork involved collecting the geological source rock and ground stone artifacts. The laboratory work involved petrographic analysis of ground stone artifacts and matching these artifacts to their associated geological sources. The Bladen region is unique in that all but two valleys have distinct materials, even though the valleys are in close proximity. The Bladen region, therefore, provides an ideal setting for reconstructing an ancient local exchange system. The purpose of this chapter, therefore, is to present the Bladen exchange case study and to satisfy two objectives. The first objective is to reconstruct an inter-community exchange network and the second objective is to investigate ground stone exchange on a larger scale for the rest of the Maya lowlands with respect to the Bladen region.

With regard to inter-community exchange, the inhabitants of all three Bladen centers exchanged ground stone tools. These centers were economically and probably politically autonomous centers even though they were modest in size and each exploited its own distinctive rock resources which were then used in the manufacturing of ground stone implements or manos and metates. Although there seems to have been a stronger demand for the lower Bladen manos and metates, there was also a reciprocal demand for what would appear to be lower grade manos and metates from the upper Bladen, resulting in a bidirectional flow of the same artifact type. This would of course mean that exchange was not governed solely by functional exchange incentives. In fact there seems to be a strong symbolic component involved in the exchange of manos and metates, which is especially apparent in local exchange contexts like the Bladen and as described by Freidel, Suhler, and Cobos Palma (1998), Freidel (1998), Garber (1989), and Garber *et al* (1998).

The export of Bladen ground stone over longer distances to other communities in the lowlands indicated that there undoubtedly were bounded local exchange networks. By bounded I do not mean that these networks did not interact with other networks in the Maya area, but rather that they did so according to different rules. For example, manos and metates from the Bladen were exported to lowland communities outside of the Bladen, but communities outside the Bladen did not reciprocate with manos and metates in the manner in which the Bladen communities exchanged manos and metates.

In addition to reconstructiong inter-community excahnge and investigating larger-scale ground stone exchange, there is another reason this case study is important. Not only is this thesis concerned with taking the first steps toward a comprehensive model of cognition, but it is also concerned with developing a procedure or methodology for applying whatever is learned to archaeology. This case study — although it plays a small role in the development of the comprehensive model of cognition itself — serves a purpose in describing how a model of cognition can be used in archaeology to propose the reconstruction of past mind frames.

Chapter 6

Conceiving of Ground Stone Exchange in the Bladen Region as a Dynamical System

Utilizing the economic approach discussed in Chapter 4 and the account of the Bladen ground stone exchange network in Chapter 5, my objective in this chapter is to propose that the Bladen exchange can potentially be modeled as a *credible* dynamical system. A credible dynamical system is a dynamical system that can be conceived of as actually existing; its existence in the present *or the past* can be supported.

By focusing on the identification of credible dynamical systems in the archaeological record, I hope to show the way in which a mathematical model can be used as an analytical tool for limiting the number of plausible interpretations of the archaeological record. I do this by constructing a mathematical model to describe a social process. In turn, this social process is seen to contribute to (or is seen to affect patterning) in the archaeological record. Through mathematical modeling followed by logical and empirical analysis of the model, the case for particular interpretation can be strengthened while superfluous interpretations that do not provide plausible results can be eliminated (Abramiuk 1999a, 1999b, 1999c). In this way, the process of mathematical modeling and analysis is seen as an exercise of elimination and not as truth detection.

Using mathematical modeling and analysis as tools for homing in on plausible interpretations or models of social phenomena, thereby eliminating the implausible interpretations, means that the dynamical systems described by the models which survive the process of modeling and analysis can be seen to constitute what I refer to as *credible* dynamical systems[1] (described by plausible models). These are dynamical systems that can be conceived of as actually having existed. Whether the particular dynamical system that is modeled and analyzed is actually the system that effected the social phenomenon in question can only be elucidated by the continuing process of proposing counter models to describe the phenomenon in an equal or more accurate manner.[2] Therefore, it is important to make clear that my approach does not lead to the claim that a credible dynamical system is the actual system that elicited the social phenomenon, but only that the dynamical system modeled is among a class of likely candidates. The approach I take moves toward an objective archaeology, but does not fall into the trap of claiming to be a pure objective approach. An illustration of how the concept of credible dynamical systems can be used to elucidate the archaeological record, and how models of such systems can be reconstructed and analyzed

[1]The term "credible" is used to emphasize that the existence of the dynamical system in question has been supported via modeling and analysis. Often, it will already be implied in the term dynamical system.

[2]My mode of inference with respect to this point is compatible with Karl Popper's (1963) notion of "falsification".

is the main point I address in this chapter concerning Bladen inter-community exchange.

In order to demonstrate that Bladen exchange can be conceived of as a credible dynamical system, a mathematical description or model of the Bladen exchange network must be constructed to test whether it is justified to claim that Bladen exchange constitutes a dynamical system. In this chapter I concentrate on the construction and assessment of a mathematical model of the exchange network; I base the model on archaeological, geological, ethnohistoric, and ethnographic data. Dynamical systems have cognitive implications. Therefore, in addition to showing that Bladen exchange can be described as a dynamical system, I go on to discuss in Chapters 7 and 8 the cognitive implications of the dynamical system for the Bladen exchange network.

The Purpose of the Mathematical Model of the Bladen Case Study for the Thesis

The mathematical model of the Bladen case study is my instrument for showing that Bladen exchange constitutes a dynamical system, which is a necessary condition for showing that it is a *cognitive system* in Chapter 7. My model describes a cognitive system, not just an economic system, since in Chapter 7 it will be shown that my model describes features to which the Bladen Maya probably would have been attuned (i.e. it is an emic model). *Attunement* has enormous implications for the study of cognition, since it suggests that exchange systems or social systems, which are shown to be credible dynamical systems, can be seen to constitute cognitive systems that operate separately from an individual's brain alone — the brain being the paradigmatic example of a cognitive system.

Before it is possible to claim that something is a cognitive system, however, one must show that it is theoretically sound to claim that Bladen exchange constituted a *dynamical system*. The mathematical model of the Bladen exchange network is integral in demonstrating the theoretical soundness of this claim. A procedure of three steps will be followed to assess the credibility of claiming that Bladen exchange can be seen as constituting a *dynamical system*. These three steps are outlined below:

1. A mathematical model of Bladen exchange must be constructed which shows that Bladen exchange can be conceived of as a dynamical system (Section 6.2). This step is essentially proposing a hypothesis. The hypothesis in this case is that Bladen exchange is a dynamical system described by the mathematical model that is constructed.

2. Measures for the values of the model's parameters are devised, and the values of the parameters are approximated using these measures (Section 6.3). This step is also essentially proposing a hypothesis. The hypothesis in this case is that Bladen exchange is a dynamical system described by the mathematical model that is constructed *with the values that have been approximated for the parameters.*

3. This mathematical model of Bladen exchange with its set parameter values, then, must be shown to produce plausible output with respect to the ethnographic record (Section 6.4). This step is essentially a test of the hypothesis that Bladen exchange is a dynamical system described by the mathematical model that is constructed with the values measured for the parameters.

It should be pointed out that most mathematical modeling applications in archaeology do *not* go through Step 2. Parameter values are usually computed by fitting the model's output to some set of time variant data. However, following a two-step procedure — instead of the three-step procedure as I have outlined — is less rigorous especially for the modeling of more complex phenomena. By going through Step 2, an extra check is set in place to prevent erroneous models of phenomena from being constructed. I explain my approach in more depth below.

6.1 The Direct Mathematical Modeling Approach

Conventionally, mathematical modeling of dynamical systems (i.e. dynamical mathematical modeling) has been used by the processual archaeological school to explain social dynamics, specifically how societies grow. The emphasis in this regard has been on explaining the emergence of "civilization" or social complexity by using a hypothetico-deductive approach which compares the output of a model (i.e. the values of the variables of a model as a function of time) with temporally variant data in the archaeological record. The assumptions that many archaeologists involved with systems modeling make is that: 1.) There is a process, typically taken to be a social or cultural process, responsible for the state of the archaeological data (Clarke 1978:42-43), and that 2.) The social process constitutes a (social or cultural) dynamical system (Clarke 1978:42-43). Once these assumptions are made (often implicitly) then one models the social process as a dynamical system using differential equations or maps (see Section 3.2.1). If a model's output fits the data, then it is said that the model or hypothesis describes a dynamical system, the behavior of which appears to explain the social process that has generated the data. In other words, because the archaeological data compares well with model's output, the social phenomenon in question can be explained as a dynamical system represented by the model being posited. The approach taken in this chapter with regard to mathematical modeling is theoretically compatible with the approach discussed above, but the method I involve in testing is different and, though the approach taken in this chapter is not commonly utilized in archaeological analysis, it is just as effective, if not more effective, than the approach that typically has been used.

The emphasis of my methodological approach, which I refer to as the *direct approach*, is based entirely on describing the social phenomenon in question down to the very measures to approximate the parameters in the model. It is only when the model has reached this degree of detail that the output of the model is compared with data. Overlooking the "description phase" is a methodological error which can have a detrimental effect on one's analysis. The parameters of a model for all intents and purposes define the model. If the social process being investigated does indeed constitute a (social) dynamical system, then the model meant to reflect the dynamical system must be shown to be plausible and this can only be done if the values selected for one's parameters make "theoretical sense". This is to say that: 1.) the measures devised for approximating the values of the parameters make "theoretical sense", and 2.) the values themselves make "theoretical sense", which can be tested by comparing the model's output with actual data. If both of these steps are adhered to, then one's proposal that the social phenomenon being investigated constitutes a credible dynamical system described by the model being posited is more easily defendable from the accusation that there are a profusion of models that can fit a given data set. This criticism in general has been a weakness in mathematical modeling procedure in archaeology and a contributor in the downfall of the concept of the "system" in archaeology. This is because if there are a multitude of models of dynamical systems that generate the same results as one's hypothesized model, then the credibility of one's explanation of the social phenomenon in question as a particular dynamical system is greatly diminished.

It is important that I clarify that the models I am referring to here are dynamical in the sense that they are used to describe actual dynamical systems. The dynamical mathematical model constitutes a differential equation or a system of differential equations which describes an actual dynamical system, whose states are represented by the model's variables and whose constraints are denoted by the model's parameters. The variables constitute functions of time and whereas the parameters constitute constants.

6.1.1 The Importance of a Model's Parameters and Two Approaches for Determining Their Values

Depending on the goals of the modeler, it is frequently the case that numerical values need to be computed for the parameters in the model of the social phenomenon in question. For the analyst whose goal it is to demonstrate that a social phenomenon constitutes a credible dynamical system, the parameters that describe the constraints of dynamical systems are probably the most important features in a mathematical model. This is because parameters need to be assessed if there is to be any theoretical feasibility to the claim that a social phenomenon constitutes a dynamical system.

The values of the parameters of a model describing a dynamical system can be ascertained using two approaches: an indirect approach or a direct approach. Which one of the two approaches an archaeologist uses to ascertain the values of the model parameters, depends on the hypothesized dynamical system that the archaeologist is modeling and the kind of data available to the archaeologist.

Indirect Determination of Parameter Values

In the indirect approach the values for the parameters of models are *ascertained.* That is, the values for parameters in models generally are ascertained by seeking the values that fit the model's output to some temporally variant data set.[3] This stands in contrast with directly *measuring* values for the parameters of a model, which is the hallmark of the direct approach to be discussed in the next section.

In the indirect approach, a model describing some social phenomenon is adopted from non-archaeological literature and then transposed onto an archaeological case study and utilized in explaining a certain set of temporally variant archaeological data in terms of a dynamical system. Eighmy's (1979) work is a perfect example of this. Eighmy is interested in demonstrating the veracity of the claim that population growth was density dependent among the Anasazi pueblos. The model he uses is based on the logistic differential equation (i.e. $\frac{dx}{dt} = ax - bx^2$), the solution of which is a well established growth model for many organisms including humans. Here, the population reflected in the cumulative distribution of cut timber for roofs, denoted by x, grows at a rate represented by the parameter, a, and diminishes at a rate

[3]By *temporally variant* archaeological data, I mean archaeological data that are changing through time. For the mathematical modeler, the temporally variant archaeological data are synthesized in such a way that they may be regarded to be representative of the states of some (social) dynamical system, described by the variables of a mathematical model. That is to say that the archaeologist implicitly hypothesizes that the temporally variant archaeological data are the product of some (social) dynamical system and that the archaeological data represent the states of this system. Thus, in considering the archaeological data, one is in fact considering the states of a hypothesized dynamical system.

represented by the parameter, b.

The way the indirect method determines the values of parameters is by varying them in the model until they generate the best fitting output to the archaeological data. Each parameter value produces an associated model output which is then fitted to the temporally variant data points obtained from the archaeological record. The goal of the fitting procedure, then, is to arrive at the best fit between the model's output through time and the archaeological data points though time. When the best fit is computed, the associated parameter values which were used to generate that best fitting model output are the values determined to be the correct values. Often, this fitting is accomplished through least squares regression (Shennan 1997:135-144) and is frequently depicted graphically as the model output (i.e. a trend-line) among actual data points in the archaeological record. The goodness of fit between the trend-line of the model's output and the archaeological data is in effect determined by an R-squared value — a high value implying a good fit and a low value implying a poor fit.

How an analyst using the indirect approach is able to *explain* a social process often goes unnoticed by the analyst. However, this still does not change the fact that there is an epistemological foundation underlying the indirect approach. In the indirect approach, an explanation of the archaeological data is achieved when the model of the hypothesized dynamical system produces output that concurs with the set of archaeological data reflecting the states of the (social) dynamical system. That is, when a model's output and a dynamical system's states coincide, one's model explains the social process in question — it explains the process as the result of a dynamical system. An example of an explanation of this kind can be found in Eighmy's (1979) research discussed above. In applying the indirect approach to his Anasazi case study, Eighmy ascertains the values of the parameters in his model by fitting the output of the model to actual data (i.e. in his case, cumulative distribution of cut timber for roofs). The fact that the the output generated by the model can be made to fit the time variant data is seen by Eighmy as support for his explanation of how Anasazi population grew – the population grew in a density-dependent fashion described by the logistic model.

The key point to remember with regards to the indirect approach, however, is that the parameter values are not really tested since they are not independently measured. Rather the values for the parameters are arrived at by fitting the output of the model to the data. In other words, the parameters are inductively obtained. An indirect modeling procedure, such as the one I have just described, can be used in obtaining an explanation of the social process in question along with a mathematical description of the process, but it is wise to note that such a procedure can be made more rigorous if the parameters are tested instead of arrived at inductively. Indirect determination of parameters is an extremely useful procedure to determine parameters in models describing straightforward or well-understood dynamical systems (e.g. population growth and supply and demand). This is because the models that describe these kinds of dynamical systems are extremely well established in describing their associated social processes and because they make "theoretical sense" (Eighmy 1979:209). However, in more complex dynamical systems, particularly nonlinear dynamical systems, the number of possible models that makes "theoretical sense" increases, and it therefore becomes necessary to test the assumptions upon which the measures for the parameters are based.

Direct Determination of Parameter Values

There does exist another approach for ascertaining values for the parameters of a dynamical mathematical model. A model can be constructed from scratch using archaeological data to describe a specific social process hypothesized to have existed in the past. In this approach the archaeological data serve as a means for measuring the values of one's model parameters directly rather than indirectly by fitting model output to time variant archaeological data. Whereas, in the indirect approach, archaeological data represent the states of a hypothesized dynamical system (i.e. the dynamical system's output), in the direct approach, archaeological data are used to devise ways to conceive of the constraints of a hypothesized dynamical system. Thus, in considering the archaeological data, the direct approach is concerned with the constraints of the hypothesized dynamical system, rather than its states as is the case for the indirect approach.

The objective of the direct approach is to use the archaeological data to approximate the values of the parameters of the model describing a (social) dynamical system. In the direct approach, *explanation* of a social process is achieved when theoretically satisfactory measures for its model's parameters are devised *and* when the model produces plausible output (i.e. variables), which compares well with what would be expected if the social process constituted a dynamical system described by the model. Ideally, temporally variant archaeological data would consist of useful state values against which one could test the model's output, but this need not be the case. The fact that the model in the direct approach is constructed to describe a particular social process and the fact that the parameters themselves are directly approximated from the archaeological record provides the model with a lot of opportunity to generate implausible output. So as long as the output produced by the model is plausible (e.g. with respect to ethnographic and or ethnohistoric data), it can be seen to pass the test of veracity. In short, two things can be seen to be happening. The first is that, in testing a model's plausibility, one is supporting the notion that the social process in question constitutes a dynamical system. And the second is that in testing a model's plausibility, one is being provided with a description of this dynamical system in the form of a mathematical model.

The way the direct method estimates the values of parameters is by independently deriving measures for the parameters based on reasoning and information gleaned from the archaeological record. While independently deriving measures for parameters is not commonly used in the archaeological record, it is commonly utilized in economics as well as the hard sciences, such as physics. In physics, parameter values need not be obtained through fitting model output to data, but can be obtained directly. To take a paradigmatic example from physics, suppose we are provided with the model, $m\frac{dx}{dt} = 3x$, which is meant to describe the momentum (i.e. $\rho = 3x$), of a mass, m, along the earth's surface at sea level. Further suppose that we do not know what the value for the mass, denoted by the parameter m, is, but we do know what its weight, W, is. In physics, there is no need to fit the solution of this linear differential equation to a time variant set of empirical data gathered by observing the displacement, x, of the mass through time. Instead, the value for m can be obtained independently using a measure derived by Newton himself, which is that mass times acceleration equals force (or weight) (i.e. $W = ma$). From this simple measure for force, one can easily obtain the value for m by dividing the weight W by a (i.e. a is simply the earth's gravitational acceleration at sea level, namely $9.80m/s^2$). In effect, the fact that the values of the parameters can be obtained directly rather than indirectly strengthens the plausibility of the model, $m\frac{dx}{dt} = 3x$. That is, the model makes "theoretical sense" because the measures for the parameters do and, as such, it can be stipulated that the dynamical system which the model describes constitutes a credible dynamical system.

The direct approach is especially useful in hypothesizing nonlinear models, where a model may have a profusion of different outputs that can fit a given situation. Take the logistic model used to model population growth, defined by $\frac{dx}{dt} = ax - bx^2$, where x denotes the population as a function of time, and a and b are parameters describing the rates of growth and stabilization, respectively. The output of this model is not necessarily unique to this model. In fact, there are a multitude of models that can more or less mimic the output generated by the logistic model if the parameters and initial conditions of the models are chosen properly. Three such models that can mimic the logistic model's output are: $\frac{dx}{dt} = ax - \frac{1}{be^{-cx}}$, $\frac{dx}{dt} = ax - bx^3$, and $\frac{dx}{dt} = ax^2 - bx^4$.

In general modeling procedure, it can be stated that the lower the *a priori* probability of building an invalid model, the less we learn from a good fit between model output and a set of temporally variant data (Mark Lake, personal communication 2004). The motivation behind the direct approach, therefore, is to increase the *a priori* probability of building an invalid model. That way, a good fit between model output and real data becomes considerably more significant to the analyst. By independently deriving the measures for the parameters, the *a priori* probability of building a bad model is increased. This is because there are now more opportunities for the model to go wrong (e.g. the derived measures for the parameters could be wrong, the general structure of the model could be wrong). Therefore, as a result of independently measuring the parameters, much more is learned from a good fit between a model's output and a set of time variant data. If, then, the model, for which measures have been devised and approximated for the parameters, does produce output that coincides with actual temporally variant data, it is reasonable to propose that the model is a plausible one. This is because the odds that a model, which is constructed from scratch with independently derived measures for its parameter values, produces plausible output are extremely low — far too low to be chance occurrence. Whereas the direct approach may not be the best method for obtaining precision estimates for the parameters of a model, it is an extremely rigorous method that can be used to support the notion that the social process being modeled constitutes a credible dynamical system described by one's model.

An important point to remember is that, in the direct approach, parameter values function as hypotheses which are subsequently supported deductively. In the direct approach, the parameter values are computed by measures independently derived by the archaeologist, and the values are supported deductively since the values are tested when the model is shown to generate realistic output using the parameter values. In this way, the values of the parameters are tested, while the explanations of the measures derived for approximating the parameter values argue the theoretical feasibility of using those parameter values in the first place. In any new model being constructed, the direct approach is critical since it enables the modeler to make "theoretical sense" of a model. This cannot be done if parameters are computed *solely* by fitting a model's output to temporally variant archaeological data. It is through the direct approach that one can show support for the fact that what is being modeled constitutes a credible dynamical system.

Discussion of Approaches to Determining Parameter Values

What has been provided is an outline of two different approaches that an archaeologist can use when modeling dynamical systems. The conventional way models are constructed is by adopting models from other disciplines. Archaeologists involved in mathematical modeling, however, must move beyond adopting models from population studies and other disciplines and begin constructing models of their own using the archaeological record as the basis for the information with which to construct the models. Information from the archaeological record and ethnographic and ethnohistoric sources can be used to construct a mathematical model as well as be used to devise measures for the values of the parameters in the model.

As I have alluded to throughout this section, both indirect and direct approaches are necessary. The indirect approach can be employed on well established models and for the final stages in achieving accuracy in the values of one's parameters (i.e. fine-tuning). The direct approach is necessary for constructing models which are complex and models in which theoretical veracity must be demonstrated. The ideal situation, then, is one in which the archaeologist has access to temporally variant archaeological data reflecting the output of the (social) dynamical system one is proposing existed, as well as archaeological data from which the values of parameters may be measured. Unfortunately, the archaeological record is such that it is often depleted of one or the other kind of data. For those analyses where there are temporally variant archaeological data, the indirect approach is obviously the easiest way to model a social process. On the other hand, if there is more information pertaining to how the parameters of a model should be measured, then clearly the direct approach should be used. Both approaches have their weaknesses. For the indirect approach it is the problem of showing that the model makes "theoretical sense", and for the direct approach the problem seems to be attributed to a lack of precision of the parameters' values. The modeler in either case must work to the best of his or her ability with the imperfect data to which he or she has access. In the case of the Bladen Branch communities, there is much more evidence pertaining to the parameters of the model that I construct, and this means that the direct approach will be utilized.

6.2 Mathematical Modeling Classic Maya Exchange Along the Bladen Branch in the Maya Mountains

The objective of this chapter is to show how Bladen ground stone exchange can be conceived of as a dynamical system. In order to accomplish this I must use mathematics, specifically differential equations, to preserve the conceptual purity of the notion of a dynamical system as was discussed in Section 3.2.1. It is also important to describe Bladen exchange mathematically in order for Bladen exchange to be reproduced and in so doing to be provided with output which can then be compared with ethnographic data. A close resemblance of the output of the mathematical model and ethnographic data will indicate that ground stone exchange can be regarded as a credible dynamical system and that the mathematical model describing it is an accurate one. Ascertaining the credibility of Bladen exchange as a dynamical system is the subject matter of Section 6.4.

The purpose of this section is to construct a mathematical model of Bladen exchange. The mathematical model constructed in this section describes the manner in which manos and metates were produced and distributed among the Bladen communities — the output of the model being the number of manos and metates that accumulated at the households of the communities. The model I construct could be regarded as a *macroeconomic model* (Turner 1993:24-33) describing economic growth with respect to one good, namely manos and metates, rather than a model involving transactions. In this way, exchange is an implicit feature in the model. That is, manos and metates were being supplied to consumers and in return, the suppliers were given goods and/or services in return. But what these goods were that were exchanged for the manos and metates is not important for this model, since my model is looking at only one side of the exchange process — the supply side — and the resulting manos and metates that accumulated at the households.

As I have already discussed in Section 5.8, the kind of exchange that was responsible for the movement of ground stone within the Bladen region was different from the exchange that was responsible for the movement of ground stone outside the Bladen region. Whereas the movement of ground stone within the Bladen was bidirectional, comprising a recurrent network, the movement of ground stone between the Bladen sites and the larger lowland sites outside of the Bladen was unidirectional. This probably had something to do with the fact that much of long-distance trade was down-the-line trade and was therefore segmented.

This segmentation would have had the effect of destroying any original contextual symbolism that ground stone held for the inhabitants of the Bladen region. That is, the ground stone would not have had the same meaning for the inhabitants of the communities outside of the Bladen that imported the Bladen ground stone as it had for the inhabitants of the Bladen communities. This would imply that Bladen exchange constituted a *system*.

6.2.1 Bladen Ground Stone Exchange as a Dynamical System

A **system** is an interrelated "network of attributes or entities forming a complex whole" (Clarke 1978:43). The notion of a network described as a "whole" would imply that a system is *bounded* (van Gelder and Port 1995:5). I identify the interrelated entities and the boundedness in Bladen exchange below:

- The *interrelated entities* in Bladen ground stone exchange constitute the members of households within the different communities that were engaged in the production, distribution, and utilization of the ground stone implements. The flow of ground stone and its associated effect on the level of ground stone at the households constitutes the means by which these entities were related.

- Bladen ground stone exchange is *bounded* by the manner in which manos and metates were regarded, which clearly was different from the way they were regarded outside of the Bladen region. This difference in meaning that manos and metates held can be inferred by the differences in the directions that manos and metates moved within the Bladen region and outside the Bladen region.

There is something fundamentally different between an exchange system in which transactors from different communities could have frequent one-on-one interaction with each other (i.e. local exchange) and an exchange system in which one-on-one interaction was infrequent (i.e. long-distance trade). Because of the proximity of the communities, Bladen exchange would have been the kind of exchange in which there would have been one-on-one contact. Exchange would have been utilized to maintain social relations between the members of different communities. This would have opened up informational channels between the members of different communities which would have been necessary if ground stone was to have meaning for the transactors, that is, if there was to be any inter-community understanding of how ground stone implements were to be utilized. By maintaining these ties, not only was exchange used to establish a fluid system of communication whereby individuals could exchange information and socialize, but it enabled the ground stone tool producer to build up a regular clientele or demand for his ground stone, and in so doing keep the movement of ground stone flowing between the Bladen communities.

A *dynamical system* is a system that changes through time (Hirsch 1984:3), and this again describes Bladen exchange. Populations rise, people utilize manos and metates in food processing and rituals, and as a result manos and metates fall out of circulation necessitating the need to replenish the implements. As a result I will consider ground stone exchange in the Bladen region to be a dynamical system throughout the modeling process. I make this assumption initially with the knowledge that in Section 6.4 I will assess the credibility of conceiving of Bladen exchange as a dynamical system. If the model produces plausible output the conception of Bladen exchange as dynamical system is supported and so is the assumption with which I started. If the model produces very different output, then the conception of Bladen exchange as a dynamical system in the way I have modeled it is not supported.

As I have already explained in Section 3.2.1, dynamical systems can be described using differential equations and I will utilize this means to describe the Bladen exchange system. I begin with the important macroeconomic concept of *production.*

6.2.2 Ground Stone Production in the Bladen Region

There are problems with blindly adopting modern economic equations to describe production in the Maya area. This is because modern economics relies on the notion of physical capital for motivating production and there is no evidence to suggest that physical capital was integral in driving production in the Maya area (Abramiuk 2004). Also, modern macroeconomic equations are based on the assumption that economic systems are stable (i.e. a substantivist assumption), and therefore economists depend on production functions in the models of economic systems which can force the models of these economic systems into stability (Uzawa 1963; Inada 1963). What is needed for ground stone production is a simple production function that does not rely on the notion of physical capital and which is not built on the *a priori* assumption that production induces economic stability. Attempts have been made to introduce the notion of social capital as a substitute for physical capital (Abramiuk 2004), but the problem with introducing social capital in place of physical capital is that it requires more data on how Classic Maya engaged in exchange than is presently available. Another problem is that we must in some manner be able to measure social capital, which is not entirely impossible, but it requires an external index with known social capitalistic characteristics. As a result, the social capital approach sometimes leads into the area of speculation.

The production function, which I propose for the average Classic Maya household is a linear production function defined by:

$$f(x_j) = rx_j \tag{6.1}$$

In this production function:

- $f(x_j)$ is the output in number of manos and metates being produced at a community, C_j.
- x_j is the input and represents the frequency (level) of manos and metates being utilized at an average household in community, C_j.[4]
- r is the rate at which a unit of input is converted into output or, specifically, the rate a mano and metate being utilized at an average household triggers the production of newly manufactured manos and metates. The rate, r, will be taken to be proportional to the rate at which manos and metates are depreciating through usage, which will be discussed in the next subsection.

The production function defined by Equation 6.1 does not rely on capital as did the previous production function and it therefore assumes that the number of manos and metates must be replenished as soon as one is taken out of circulation either through ritual or through depreciation in the food-processing process. Equation 6.1, therefore, can be said to be driven simply by the need to maintain a certain level of manos and metates in the household.

[4]The *average household* is defined as a group of individuals that engage in production and consumption together. In other words, the household is considered to be an economic unit which arises out of economic necessity as well as out of familial obligations or co-residential obligations. It will be assumed that the household coincides with the residents of a dwelling, since co-residents often work and live together. The number of members in a household or economic unit may vary and this is reflected in the size of the dwelling (Naroll 1962). Settlement area can be translated into population using Naroll's (1962) formula of $10m^2$ of settlement area per person. This estimate agrees with the ethnographic evidence and is the most dependable estimate that Maya archaeologists have, as I argue in Abramiuk (1998).

Also, note that this model does not suffer from the same assumption of diminishing returns to production and as a result, no assumption as to the economic system's stability in which it is featured is made.

6.2.3 Depreciation of Manos and Metates and Model for Exchange in the Bladen Region

As I alluded to in the last subsection, production is driven by the need to replenish depreciating manos and metates (i.e. manos and metates that are falling out of circulation either through ritual or domestic wear as well as population growth). Like the production function described by Equation 6.1, mano and metate depreciation can be represented by a linear differential equation, namely:

$$\frac{dx_i(t)}{dt} = -(n + \delta)x_i(t) \tag{6.2}$$

In this model:

- $x_i(t)$ describes the mano and metate frequency (i.e. the number of manos and metates in use) through time at the average household in community, C_i.
- $\frac{dx_i(t)}{dt}$ describes the change in frequency of manos and metates per average household per unit time.
- n is the population growth rate.
- δ is the rate of depreciation of manos and metates that are falling out of circulation either through ritual or domestic wear.

Equation 6.2 describes the situation where the frequency of manos and metates per average household naturally decreases as manos and metates wear down or taken out of circulation. Similarly, the frequency of manos and metates per average household should decrease as the number of households grows. The premise behind this latter point is that a growth in households will effectively decrease the amount of manos and metates for each household incrementally. That is, as the number of households rises, there will be less manos and metates to go around to each household.

Together the production function described by Equation 6.1 and the differential equation for depreciation described by Equation 6.2 forms the following differential equations for i number of production centers:

$$\frac{dx_i(t)}{dt} = -(n+\delta)x_i(t) + \sum_{j=1}^{m} c_{ij}\rho_j r x_j(t) + I_i(t). \tag{6.3}$$

In this linear differential equation:

- $x_i(t)$ describes the mano and metate frequency (i.e. the number of manos and metates in use) through time at the average household in community, C_i.
- $\frac{dx_i(t)}{dt}$ describes the change in frequency of manos and metates per average household per unit time.
- $x_j(t)$ is the input and represents the frequency (level) of manos and metates being utilized with respect to time at an average household in community, C_j.
- m is the total number of production centers or communities in the inter-community exchange network being considered.

- r is the rate at which a unit of input is converted into output or, specifically, the rate at which a mano and metate being utilized at an average household triggers the production of newly manufactured manos and metates.

- n is the population growth rate.

- δ is the rate of depreciation of manos and metates that are falling out of circulation either through ritual or domestic wear.

- ρ_j is community C_j's proportion of the output produced in the inter-community exchange network being considered (i.e. $c_{ij} \in [0, 1]$). It represents the relative economic strength of the community doing the producing.

- c_{ij} is the the proportion of output produced from a particular community, C_j, which is being allocated to C_i (i.e. $c_{ij} \in [0, 1]$). The parameter, c_{ij}, is ultimately influenced by what the producers of manos and metates at C_j were getting from consumers at C_i in exchange for the manos and metates.

- $I_i(t)$ an external input consisting of imported manos and metates from outside of the inter-community exchange network in question.

6.2.4 Rewriting Equation 6.3

The last subsection has provided some insight into how we may fit Equation 6.3 to the three economic hubs in the Bladen region. By utilizing the notion that imports can be regarded as goods absorbed into the Bladen system, we can rewrite Equation 6.3 in the following way:

$$\frac{dx_1(t)}{dt} = -Ax_1(t) + r\{[k_{11} + k_{1I}]x_1(t) + k_{12}x_2(t) + k_{13}x_3(t)\} \qquad (6.4)$$

$$\frac{dx_2(t)}{dt} = -Ax_2(t) + r\{k_{21}x_1(t) + [k_{22} + k_{2I}]x_2(t) + k_{23}x_3(t)\} \qquad (6.5)$$

$$\frac{dx_3(t)}{dt} = -Ax_3(t) + r\{k_{32}x_2(t) + [k_{33} + k_{3I}]x_3(t)\}, \qquad (6.6)$$

where $A = n + \delta$ and $k_{ij} = c_{ij}\rho_j$. (Note that $k_{iI} = c_{iI}\rho_I$ and it designates the proportion of imports from outside of the Bladen being allocated to each of the Bladen sites, C_i.) In these equations, $x_1(t)$ is the frequency of manos and metates in the average household at Muklebal Tzul, $x_2(t)$ is the frequency of manos and metates in the average household at Ek Xux, and $x_3(t)$ is the frequency of manos and metates in the average household at the Lower Bladen sites, and they only represent nonnegative numbers.

As the reader can see, the above three coupled linear differential equations can be used to describe how ground stone levels or frequencies changed continuously through time at the average household in each of the Bladen communities. The dynamical system, however, that these equations describe is unstable for the values I have estimated. This would imply that households would have no limits on the quantity of ground stone they maintained. Since this is unrealistic, a saturation point will be introduced, which will act as a controlling mechanism for the system.

It seems reasonable to expect that producers would not increase production of manos and metates just because the quantity being consumed by a household kept on increasing. The lack of extremely large amounts of manos and metates at households suggest that there was a point at which producers began supplying households at a constant rate rather than an increasing rate.

In the beginning of the Bladen system's development there were undoubtedly households that did not even have enough manos and metates for all of the food-processing that was required of a household. As such it seems reasonable to assume that the rate at which producers supplied manos and metates to households would have increased until this threshold was reached. And after the household frequency of manos and metates had reached this threshold, production would have simply supplied households at a relatively constant rate. This is supported by the fact that there are no indications of large-scale workshops in the Bladen region which would have been required if an increasing production rate was to be sustained.

In this way, instead of using the production function $f(x) = rx$, a better approximation for the production function would be:

$$f(x_j) = \begin{cases} r\theta & \text{if } x_j \geq \theta \\ rx & \text{if } x_j < \theta \end{cases},$$

Assuming that at least two grinding implements were needed per household (two is the mode of metate frequencies in Hayden and Cannon's (1984:70) ethnographic observations), then it would appear that two manos and metates is a good approximation for the threshold, θ. That is, until the threshold is reached, manos and metates will be produced in an increasing fashion, when this saturation point of two is reached, producers will begin producing and supplying households at a constant rate.

Substituting this saturation function for the production function in Equations 6.4–6.6 gives the following model:

$$\frac{dx_1(t)}{dt} = -Ax_1(t) + [k_{11} + k_{1I}]f(x_1) + k_{12}f(x_2) + k_{13}f(x_3) \tag{6.7}$$

$$\frac{dx_2(t)}{dt} = -Ax_2(t) + k_{21}f(x_1) + [k_{22} + k_{2I}]f(x_2) + k_{23}f(x_3) \tag{6.8}$$

$$\frac{dx_3(t)}{dt} = -Ax_3(t) + k_{32}f(x_2) + [k_{33} + k_{3I}]f(x_3). \tag{6.9}$$

The mathematical model described by Equations 6.7–6.9 is what economists would refer to as an *exogenous model.* That is, the model envisions Bladen exchange as being motivated by external factors rather than internal factors and they are known as exogenous variables. These external factors, or inputs to the system, are population growth and mano and metate depreciation and are together represented by the parameter, A. Both of these inputs can be regarded as observable natural and behavioral phenomena occurring outside of the economic system in question. This is clearest with regards to population growth, but mano and metate depreciation can also be regarded as an externally observable process dictated by social environmental circumstances. These exogenous factors that pervade outside of the economic system can be described formally and measured relatively accurately.

On the other hand, accumulation of manos and metates at households constitutes the endogenous variable for the economic system. More precisely, the endogenous variables in the Bladen exchange system are the frequencies of manos and metates at the average household in each of the Bladen centers.

Equations 6.7–6.9 are deterministic in that when provided with an initial numerical state, the above equations describe the system's development through time. The development of the system can end at a final state called a *stable equilibrium*, or continue indefinitely, which is often referred to as *instability*. Every initial state in a deterministic model of a system has a unique trajectory. The equilibria that these trajectories approach is analyzed in *Appendix E*.

6.3 Approximating the Values for the Parameters in the Mathematical Model Describing Bladen Exchange

To finish constructing the mathematical model of Bladen exchange so that it may be reproduced to generate an output to be compared with the ethnographic data, it is necessary to approximate the parameters in the model. This section devises measures for the parameters in Equation 6.3 and estimates the values for the parameters. Whereas it is important to remember that the archaeological data on which I base my estimates of the values for the parameters and the methods by which I measure the values for the parameters may be imperfect, it is also important to realize that these data and methods function in effect as hypotheses which are supported when the model is shown to produce plausible output.

6.3.1 Determining the Number of Ground Stone Production Centers in the Bladen Exchange Network (m)

m is taken to be the number of centers that interact, which in the case of the Bladen is three — Muklebal Tzul, Ek Xux, and the Lower Bladen sites. The two upper Bladen sites — Ek Xux and Muklebal Tzul — will be considered to be distinct communities, whereas the Lower Bladen sites — the Quebrada de Oro Ruin and the RHF Site — will be considered to comprise a single center. I will sometimes refer to the Lower Bladen sites as a community even though technically they occupy different valleys. The reason I will refer to the two lower Bladen sites together as a community is that, as I have already stated, there is evidence to suggest that these two communities operated as a twin-community. This was discussed in Section 5.4.3.

6.3.2 Approximating the Household Growth and Depreciation Rates

The parameters n and δ will be considered to be the same for all Bladen centers, which amounts to assuming that the growth rates of the centers and the grinding implement usage rates at the centers were roughly the same. Assuming the same growth rates at the communities is a reasonable assumption, since the archaeological evidence suggests that the sites were contemporaneous, and this means that the communities' emergence on the scene was likely part of the same influx of migrants. Similarly, with regards to the grinding implement usage rates, there does not seem to be any compelling evidence at this point to suggest that manos and metates were used differently at the Bladen sites from other Classic Maya sites.

Ascertaining an Estimate for the Household Growth Rate (n)

In previous research (Abramiuk 1998), I modeled the palaeodemographic growth in the Ek Xux valley and in so doing suggested that a major reason for the abandonment of Ek Xux was that the population densities were too high to have been supported by the available resources in the valley. That is, settlement was expanding beyond the cultivable land available in the valley. The settlement area growth was exponential, indicating that the population growth conformed to a Malthusian model of growth — at least initially — in the development of the Bladen communities. In contrast to the focus of my previous research, the focus in this section will be on calculating the household growth rate rather than population growth rate. As it turns out, the rates are not dissimilar.

To calculate the household growth rate, I counted the number of house-mounds in the Ek Xux valley.[5] The mechanism that was used to explain household growth *through time* was the *developmental cycle* (Fortes 1969; Freeman 1969; Goody 1969).

The developmental cycle is a well documented phenomenon in which families or households create living areas additional to the primary household in regular intervals as new generations arise. The expansion of living areas manifests itself in the form of settlement attachments to the primary domicile. The developmental cycle has been documented among the LoDagaba (Goody 1969), the Iban (Freeman 1969), and the Classic Maya (Tourtellot 1988).

Assuming that a developmental cycle occurs every generation and that a generation is approximately 20 years (Haviland 1988, Tourtellot 1988), I estimate the household growth rate of Ek Xux to be 0.0320 (see Figure 11).[6]

[5]There could have been hidden settlement, which was not built on any platforms or mounds and so my household count is likely lower than the actual number of households that existed at Ek Xux.

[6]Assuming settlement area reflects population as Naroll (1962) proposes (i.e. $10m^2$ of settlement area per person), the population growth rate at Ek Xux is 0.0294.

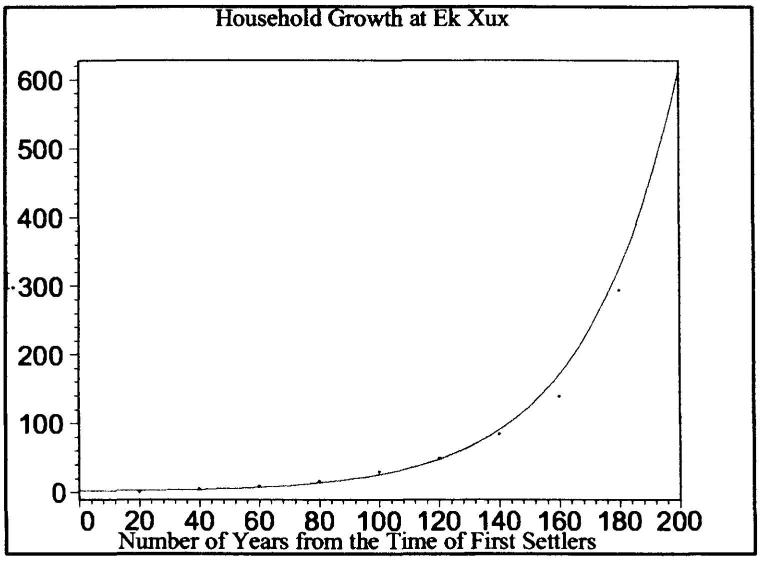

Figure 11: This plot depicts household growth at Ek Xux. The points represent the approximate number of households at every generation (20 year interval) after the first settlers of Ek Xux came into the valley. The exponential trendline fits the data well, giving a household growth rate, n, of 0.0320.

The Means By Which Manos and Metates Depreciate

The mano and metate depreciation rate is the rate at which manos and metates are diminished by those utilizing the grinding implements in domestic and ritual contexts. Wear rates of manos and metates in Maya prehistory can be inferred from ethnographic, epigraphic, and what archaeological evidence there is on the subject.

Below are the two most common means through which manos and metates depreciate:

- Manos and metates wear down in food-processing approximately every twenty years which is consistent with Hayden's (1987:15) observations.
- In addition to this grinding rate, manos and metates were used in termination rituals (Freidel, Suhler, and Cobos Palma 1998:141; Freidel 1998:190) dedication rituals or votive offerings (Garber 1989; Garber *et al* 1998:128) and even New Year celebrations (Garber 1989; Garber *et al* 1998:130), which were occasions when old household utensils were discarded (Landa, translated by Tozzer 1941:151-152). (Note: This latter occasion was likely a means of discarding utensils that had already been worn down, so it probably did not contribute to the rate of wear.)

Because the New Year was a time in which utensils were ritually destroyed in a process connoting death and rebirth, it seems logical to infer that manos and metates were used extensively in rituals in the Classic period; perhaps only the favorite manos and metates were kept for long periods of time. In addition to these ritual uses of grinding implements, manos and metates were placed in burials and in caves, as offerings throughout the Bladen region (Abramiuk 1996).

Inferring a Mano and Metate Depreciation Rate (δ)

Domestic Context It will be assumed that two manos and metates are worn down in day-to-day food processing every twenty years, which is consistent with ethnographic observations (Hayden and Cannon 1984:70).

Dedication/ Termination Context If we assume that structures are constructed and reconstructed in synchronization with the developmental cycle, then termination and dedication rituals occurred at least every 20 years. This would mean that at least one mano and metate went toward these occasions.

Mortuary Context The Classic Maya were known to have buried manos and metates with their deceased. At Muklebal Tzul we have much evidence of this occurring. I will therefore propose that approximately one mano and metate was used every twenty years in an interment.

This gives a figure of approximately four manos and metates in a 20 year interval. This means that a reasonable depreciation rate (δ) for manos and metates is 0.20.

Together, the average household growth rate (n) and the depreciation rate (δ) give a total growth rate ($n + \delta$) of 0.23.

6.3.3 Providing a Range for r

A specific value for r in Equation 6.3 is difficult to estimate and further work needs to go into ascertaining a measure for this parameter, yet the results of simulating the exchange model using the measure that I describe below seem promising.

x_i is the number of manos and metates that households have which prompts production of manos and metates. In this way, r can be regarded as a rate of response of the producer. The premise behind this rate is that the producer sees how many manos and metates people have in his community and from this information decides on how much to produce. If conceived of as a rate of production per unit of stock, an approximation for r is difficult to ascertain. However, there is another way of conceiving of this measure that facilitates in providing an estimate for its value.

How many manos and metates are produced clearly depends on the *demand* for manos and metates, which of course is dependent on whether or not there are other goods in the marketplace that can be used in place of manos and metates. In this way, r can be approximated by conceiving of it as a measure of how the use-value of manos and metates compares with the use-value of other goods rather than a rate. As defined, r is essentially a measure of how manos and metates rate with other goods in the marketplace and which serve the same purpose of manos and metates, in terms of ritual and domestic uses.

There might have been or might not have been goods that could have replaced manos and metates in doing the same things that manos and metates could do. Surely, no other implement could have been used in the same domestic context as a mano and metate, yet there may have been replacement items that could have been used in ritual activities. We know, for example that ceramics were used in dedicatory rituals, but whether they could be considered equivalents to the mano and metate is difficult to deduce unless a thorough investigation of ritual deposits is conducted. Such an investigation might be able to reveal which ceramic types were associated with ritual contexts involving mano and metate deposition which in turn can act as an estimate for the number of goods that could replace manos and metates in that particular ritual context.

Such a measure that could be based on such knowledge is:

$$r \approx \sum_{p=1}^{q} \left[\frac{1}{z+1}\right]_p ,$$

where p denotes the number of functions that manos and metates can serve, or number of contexts that manos and metates are found in, and z is the number of other goods that can serve the same function as a mano and metate (i.e. found in the same context with manos and metates). The logic of such a measurement is as follows:

- The more functions or purposes that a mano and metate serves, the more valuable it is. Thus, a large p results in a high value for the mano and metate.

- The more goods there are that can replace manos and metates in serving a particular purpose, the less valuable is the mano and metate. Thus, a large z results in a low value for the mano and metate.

Based on the information we have at this time, the number of contexts I have deduced for manos and metates is three (i.e. $p = 3$, which may of course change as more information becomes available. Remaining consistent with the contexts I have described in the subsection where I deal with mano and metate depreciation rate, δ, manos and metates are found in: food-processing contexts, dedication/termination contexts, and mortuary contexts.

In the food-processing context, only manos and metates can process food in the same way that manos and metates can process food. As for the dedication/termination contexts and mortuary contexts we know that there is *at least* one ceramic type that is found in the same context as manos and metates. Using this information we can get a value of one for the first context, and a value of at least one half for the other two contexts. This summed gives us a value range of $[1.0, 2.0]$ for r.

6.3.4 Determining C_j's Proportion of the Output of the Bladen Exchange Network (ρ_j)

ρ_j can be calculated for the Bladen communities by taking the number of artifacts sourced to a particular Bladen site and dividing this number by the total number of artifacts sampled at the Bladen sites (i.e. 116). This figure includes imported tools (i.e. 6) from outside of the Bladen region, since it is assumed that these imports were absorbed into the local Bladen exchange system. The imports, like the local stone tools, contributed to the level of manos and metates at the households and therefore to the productivity of the community. (Note that the Lower Bladen sites, namely Quebrada de Oro Ruin and RHF Site, are considered to be one source community since evidence suggests that these two communities operated in concert [refer to Section 5.4.3 where this was discussed]). Figure 12 summarizes the results of computing ρ_j for the Bladen sites as well as the sites outside of the Maya Mountains.

		Sources		
	Muklebal (ρ_1)	Ek Xux (ρ_2)	L. Bladen Sites (ρ_3)	External Sites (ρ_I)
Output Prop.	$\frac{9}{116}$	$\frac{17}{116}$	$\frac{84}{116}$	$\frac{6}{116}$

Figure 12: The proportions of the grinding implements produced for the Bladen exchange system by Muklebal Tzul, Ek Xux, the Lower Bladen communities, and the communities in the highlands.

		Destinations			
		Quebrada de Oro	RHF	Ek Xux	Muklebal
Sources	Quebrada de Oro/ RHF	25	25	16	18
	Ek Xux	1	0	12	4
	Muklebal	0	0	2	7
	Highlands	0	1	2	3
	TOTAL	26	26	32	32

Figure 13: Sampled and sourced ground stone artifacts at the Quebrada de Oro Ruin, the RHF Site, Ek Xux, and Muklebal Tzul.

6.3.5 Measuring the Proportions of Distribution (c_{ij}) Among the Bladen Sites

With respect to the parameters in Equation 6.7, c_{ij} is the proportion of C_j's material output being exported to C_i. c_{ij} satisfies the property, $\sum_{j=1}^{m} c_{ij} = 1$ assuming a closed ground stone exchange economy among the Bladen communities. Empirically, this figure can be estimated by the following proportion: the number of grinding implements from C_j found at C_i over the total number of grinding implements from C_j. Figure 13 contains all of the information necessary for calculating c_{ij}s for all of the communities.

From Figure 13 it is easy to calculate the proportions of grinding implements, c_{ij}, being produced and then distributed among the Bladen sites. I have already mentioned that this value can be measured as the ratio of the number of artifacts from C_j at C_i to the total number of artifacts from C_j. This implies first combining Quebrada de Oro and RHF into one production unit and then dividing each entry in the row by the sum of all of the entries in the associated row. The results for the c_{ij} estimates are displayed in Figure 14.

		Destinations		
		Quebrada de Oro/RHF	Ek Xux	Muklebal
Sources	Quebrada de Oro/ RHF	$\frac{50}{84}$	$\frac{16}{84}$	$\frac{18}{84}$
	Ek Xux	$\frac{1}{17}$	$\frac{12}{17}$	$\frac{4}{17}$
	Muklebal	$\frac{0}{9}$	$\frac{2}{9}$	$\frac{7}{9}$
	Highlands	$\frac{1}{6}$	$\frac{2}{6}$	$\frac{3}{6}$

Figure 14: Fractions of output from the Lower Bladen sites, Ek Xux, and Muklebal Tzul.

6.3.6 Imports and Exports

$I_i(t)$ is taken to be imported manos and metates originating from the Maya highlands of Guatemala. Imports of manos and metates, unlike exports of manos and metates, would have affected the Bladen ground stone exchange system, since the imported manos and metates would have been absorbed by the Bladen exchange system. Exports would not have affected the exchange of manos and metates within the Bladen region, since the nature of the economic relations with the Bladen communities' long distance clients would have paralleled but not impacted upon the local exchange system among the Bladen communities. Only grinding implements coming into the Bladen system will affect the frequency of manos and metates at households within the Bladen communities.

In this study, I am strictly concerned with the local economics among the Bladen communities, since the exchange relations with non-Bladen communities were undoubtedly different. As was discussed in Sections 5.8 and 5.9, the peer exchange system of the Bladen region is unique in its particulars and is characterized by *local* dynamics different from the dynamics that governed trade relations outside of the Bladen. As a result, exports were probably regarded as obligatory and the purpose of export was to maintain connections with the rest of Classic Maya civilization. In return for exporting grinding implements, the Bladen Maya would have imported all of the goods that were not found locally. In short, the motives for exporting grinding implements to the larger lowland centers were different from the motives which governed exchange of grinding implements within the Bladen region and as a result export did not impinge upon local exchange. Hence, the Bladen inter-community exchange system will be treated as being affected negligibly by exports — the exchange system's boundaries extending only as far as the symbolism of manos and metates would have permitted (see Section 5.9) — and only imports of grinding implements will be considered. The rest of this section is dedicated to computing the inputs, $I_i(t)$, for Muklebal Tzul, Ek Xux, and the Lower Bladen sites in Equation 6.3.

Whereas highland-made manos and metates undoubtedly were special for the Bladen inhabitants (i.e. the material used to manufacture the highland manos and metates was different from local material), they are found in the same contexts as the locally made manos and metates which suggests that they were used in the same way as locally made manos and metates. As such, the Bladen inhabitants would have endowed these imported objects with the same meaning that local manos and metates held. As a result, imports would have been absorbed into the system. This can be expressed by the following approximation:

$$I_i(t) \approx c_{iI}\rho_I r x_i(t).$$

The reasoning for this approximation is that $I_i(t)$, which designates the amount of manos and metates produced and supplied to Bladen community C_i, would have been relegated by the level of manos and metates at Bladen community C_i. In the case of the imports into the Bladen from outside of the Bladen, it will be assumed that because of the great cost involved in long-distance trade, the producers in the highlands would have based their production strategy on information gathered from the communities to which they were exporting. That is, highlanders would have decided on how much to supply the Bladen communities based on the number of manos and metates at Bladen households.

The parameters, c_{iI} ($i = 1, 2, 3$), can be obtained from the last row in Figure 14, whereas the parameter, ρ_I, can be obtained from the last column in Figure 12.

6.4 Assessing the Credibility of Bladen Exchange as a Dynamical System

As I mentioned at the beginning of this chapter and at the beginning of Section 6.2, it is important to construct a mathematical model of Bladen exchange so that it can be reproduced. Reproducing Bladen exchange will result in output that can then be compared with ethnographic data. Provided that the parameters in the model were independently measured, if the output of the mathematical model and ethnographic data agree, then it can be said that ground stone exchange constitutes a credible dynamical system described by the mathematical model.

In this section I assess the model by comparing the results of the model's output with ethnographic data and I propose an explanation for the results that are generated by the model.

6.4.1 Reproducing Inter-Community Exchange in the Bladen Region by Generating and Assessing Output from the Model

In order to reproduce the inter-community exchange phenomenon in the Bladen region, output from the model describing the exchange phenomenon must be generated. The manner in which a model's output is generated is by mathematically analyzing the model of Bladen exchange and or numerically simulating the model. A mathematical analysis of the model is the preferred means of assessing what the model, and hence the dynamical system, can and cannot do through time. On the other hand, a simulation of the model is a useful means of graphically representing what the dynamical system does through time. I utilize both of these means to generate the model's output and I will briefly discuss each in turn.

The mathematical analysis of this model is provided in *Appendix E.* The results of this analysis reveal that this system is quite stable. Specifically there exists a stable equilibrium, referred to as "Equilibrium II", as long as the value for the parameter r lies within the range $[0.83, \infty)$, which of course it does (recall that the hypothesized range for r is $[1.00, 2.00]$).

Figure 15 depicts the results of simulating inter-community exchange in the Bladen region, based on the mathematical model described by Equations 6.7–6.9). What is shown by this figure is how manos and metates accumulated at households within the Bladen region and how they eventually reach a

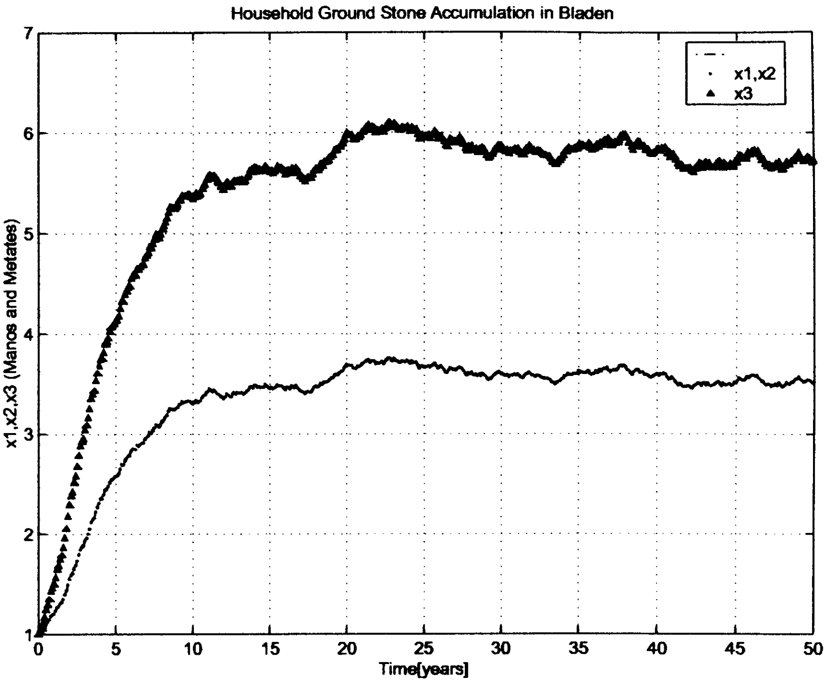

Figure 15: This plot depicts the results of the dynamical system described by Equations 6.7–6.9, where r is randomly fluctuating in the range [1,2]. This uniformly random fluctuating parameter causes the deterministic system, described by Equations 6.7–6.9, to respond in a stochastic manner. The diagram shows how the household level of manos and metates at Muklebal Tzul (x1), Ek Xux (x2), the Lower Bladen sites (x3) grew through time. Mano and metate frequencies at households in Ek Xux and Muklebal Tzul approach the same equilibrium point along the same trajectory, whereas the frequency of manos and metates at households in the Lower Bladen sites approaches an equilibrium point along a trajectory well above Muklebal Tzul and Ek Xux.

stable equilibrium. More work needs to be conducted with regard to homing in on the parameter values of the model more accurately, but the exchange model constructed, thus far, looks promising in describing mano and metate accumulation. The trajectories denoting mano and metate frequencies per average household in the Bladen lie well within ethnographic specifications[7] for the Maya highland communities of Aguacatenango, Chanal, and San Mateo — a range of [0,9] for manos and a range of [0,8] for metates (Hayden and Cannon 1984:70,77) — and this means that Bladen exchange as it is described by Equations 6.7–6.9 constitutes a plausible dynamical system.

According to Figure 15, the average frequencies of manos and metates per household in the Bladen are greater than the mean frequencies in the ethnographic data — which I calculate from Hayden and Cannon (1984:70,77) to be 2.40 for manos and 1.94 for metates — but this could be due to the fact that the average frequencies of manos and metates really were greater in the Bladen during Classic times. One reason which might explain why mano and metate frequency was greater in the Bladen is that mano and metate frequency had a greater significance for the Classic Maya inhabitants. I discuss this in more detail below in pages 299–300, but before I do this I should drive home the idea that the model and the measures I devise to approximate the parameter values, when the model's output is tested against the ethnographic data, are credible. Moreover, the credibility of the model reaffirms the hypothesis that Bladen exchange does constitute a dynamical system.

[7]According to Hayden and Cannon (1984), at the time they collected their ethnographic data, highland Maya life in the communities that they investigated had not significantly changed since before the Spanish Conquest, and so the data collected by them is suggested to be representative of the way in which Classic Maya would have lived.

A Brief Analysis and Discussion of the Credibility of the Model, Its Parameters, and the Dynamical System It Describes

To demonstrate the plausibility of the model and the credibility of the dynamical system it describes, one needs only to show that the output of the model conforms to ethnographic specifications with the values that were approximated for the parameters in the model. In demonstrating this one point, provided of course that the explanations of the measures derived for approximating the parameter values make "theoretical sense" (see Section 6.3), what is shown is that the model and its parameter values are realistic. As a result, because the output of the model is consistent with the ethnographic data, the model and the dynamical system it is supposed to describe are substantiated. I will demonstrate what I mean by analyzing a few of the parameters.

The only parameter in the model for which I had no approximation and for which a range had to be hypothesized was the parameter, r. The reasons for inferring the numerical range for r are detailed in Subsection 6.3.3; the range for r was reasoned to be: $[1.00, 2.00]$. This selected range of parameter values, which I will denote by r_s, will clearly have an associated range of output values from the system, which I will denote by x_s.

The model and the underlying dynamical system it describes can be shown to be credible if the hypothesized values help the model to generate plausible output. To do this, it needs to be shown that any output $(x \in x_s)$ produced by an associated parameter value $(r \in r_s)$ is contained in the ethnographic range of output, which I will denote by x_e (i.e. recall that this range is [0,9]). By "any output", I mean of course the entire trajectory $x(t)$. However, since it can be assumed that $x(t) \geq 0$ for all t and that the initial conditions are smaller than the equilibrium values,[8] it needs only to be

[8]The fact that initial conditions are smaller than the equilibrium values is reasonable

shown that the equilibrium values of our model's output (with the selected range of parameter values, r_s) and not the entire trajectories lie within the ethnographic output range, x_e (i.e. $x_s \subseteq x_e$).[9]

Because we are dealing with only the equilibrium values then clearly x_s and x_e can be seen to be functions $\phi(r_s)$ and $\phi(r_e)$ of the parameters r_s and r_e, respectively. In other words, $x_s = \phi(r_s)$ and $x_e = \phi(r_e)$. Therefore, to show that any output ($x \in x_s$) produced by an associated parameter value ($r \in r_s$) is contained in the ethnographic range of output ($x \in x_e$), it needs only to be shown that $\phi(r_s) \subseteq \phi(r_e)$.

What needs to be computed, then, to determine whether this relationship stands is $\phi(r_s)$, since we already know $\phi(r_e)$ (i.e. it is $[0, 9]$). Substituting my selected range of values, r_s, into the function, $\phi(r_s)$, describing the equilibrium value for the system gives a range that does indeed agree with the relationship $\phi(r_s) \subseteq \phi(r_e)$, since $\phi(r_s) = [2.40, 7.80]$.[10]

What this short analysis demonstrates is that the output of the system could have produced results outside of the ethnographic range, had different

to expect since it is only later in an economic system's development that households would have had an opportunity to accumulate manos and metates.

[9]It can be assumed the ethnographic range, [0,9], approximates very nearly an equilibrium range for the ethnographic system. According to Hayden and Cannon's (1984) ethnographic observations, it would seem that the number of manos and metates was beginning to diminish due to the advent of new technology, specifically mechanical grinders, and so it can be assumed that the ethnographic system was entering a transition period of instability. Thus, if we extrapolate to before this transition, then the range [0,9] can be considered to be nearing the end of a long and enduring equilibrium, which may have stretched back into Classic times as Hayden and Cannon seem to argue.

[10]Basically this range was computed by going to the analysis of "Equilibrium II" in *Appendix E* and substituting the minimum and maximum values of the range r_s into the function for the equilibrium while keeping all of the other parameter values in the function as they were.

hypothesized values for r been selected. And this would mean that Bladen exchange would not be considered to be a credible dynamical system, since its model would not have produced the results expected of it. Fortunately, the hypothesis that r should lie in the range $r_s = [1.00, 2.00]$ withstood the test against ethnographic data. That is, any r within the range, r_s, will indeed produce output well within the output range dictated by ethnographic observations.

Basically, what I am saying is that the procedure for modeling and testing acts as a sort of check-and-balance system, and this limits what can be and what cannot be considered to be a credible model (i.e. a model describing a credible dynamical system). In general, then, modeling and testing can be seen as steps in a process by which possibilities are being limited and certain explanations are being shown to be better than others.

This same check-and-balance system is also at work with the other parameters in the model as well. Take the allocation coefficients (c_{ij}) that were obtained from the archaeological fieldwork and labwork. These parameters mainly affect the *relative* magnitudes of the output values, but they also affect the actual magnitudes of the output values like r does. Had the results of the sourcing analysis in the Bladen case study revealed a different distribution of artifacts, which would have consequently changed the values for c_{ij}, a different output would have been generated which could be seen to be *inconsistent* with ethnographic observations. For example, say that in place of Figure 14 my archaeological investigations found the distribution of artifacts to be represented by Figure 16, where A, r, θ, and ρ_j were as they were (i.e. $A = 0.23$, $r = 1.50$, $\theta = 2.00$, $\rho_1 = 0.08$, $\rho_2 = 0.15$, $\rho_3 = 0.72$, and $\rho_I = 0.05$). Then the model will generate output values outside of ethnographic specifications. And this would of course imply that the model and the dynamical system it describes are not credible hypotheses. In this particular hypothetical case, the number of manos and metates per household at the lower Bladen communities would be 9.78, which is of course greater than 9, the upper limit of the ethnographic range.

		Destinations		
		Quebrada de Oro/RHF	Ek Xux	Muklebal
Sources	Quebrada de Oro/ RHF	$\frac{80}{84}$	$\frac{2}{84}$	$\frac{2}{84}$
	Ek Xux	$\frac{1}{17}$	$\frac{15}{17}$	$\frac{1}{17}$
	Muklebal	$\frac{0}{9}$	$\frac{1}{9}$	$\frac{8}{9}$
	Highlands	$\frac{6}{6}$	$\frac{0}{6}$	$\frac{0}{6}$

Figure 16: *Hypothetical* fractions of output from the Lower Bladen sites, Ek Xux, and Muklebal Tzul.

The point to be made here which cannot be emphasized enough is that different values for the parameters result in different outputs. It is not a coincidence that my model with its associated parameter values produced the results that it did, and this of course gives my model and the dynamical system it describes credibility. Because the values that were measured using data from the archaeological case study did actually produce ethnographically consistent results, the parameter values, the measures devised for the parameter values, the model which incorporates the parameters, and the dynamical system that I am assuming is responsible for the output described by the model are all given credibility.

A Discussion of the Significance of Manos and Metates

Manos and metates had and continue to have great significance for the Maya. For the contemporary Maya, the significance of manos and metates can be obtained from the ethnographic evidence. For the Classic Maya, the significance of manos and metates can be inferred from the archaeological record. According to the evidence it would seem that there were more roles that manos and metates filled during the Classic period which would suggest that more manos and metates would have been needed in the average Classic Maya household.

Ethnographic evidence from the Maya highlands (Hayden and Cannon 1984:74) suggests that the frequency of manos and metates is greater in households of lineage heads. Hayden and Cannon's explanation for why manos and metates are accumulating in households of lineage heads is that lineage heads maintain a surplus of manos and metates to lend or give away to lineage members in need of manos and metates, which are used mainly for food processing. The process by which the high status household donates a mano and metate to a needy household obligates the needy household to return the favor in some way. This reinforces the role that the lineage head holds, which is the role of provider, and increases the social status of the lineage head and his household. In this way, mano and metate frequency is very closely associated with social status.

The significance of manos and metates for the contemporary Maya is similar to significance of manos and metates for the Classic Maya, but it was probably magnified in the case of the Classic Maya. The importance that manos and metates held for the Classic Maya can be inferred from the archaeological contexts in which manos and metates are found. These contexts are mainly ritual contexts as well as domestic contexts. That is, manos and metates were used for various offerings and rituals as well as for food processing. I discussed this in depth in Section 5.9 as well as in pages 283–284. Having a significant surplus of manos and metates would have indicated self-sufficiency and, much like social status, it would have been a feature to which the Classic Maya would have paid attention.

As I stated above, the frequencies of manos and metates generated by the model that I constructed of Bladen exchange fall within the range provided by the ethnographic data, but they are slightly higher than the mean frequency derived from the ethnographic data. If we interpret the archaeological and ethnographic evidence above, an explanation for the slight discrepancy could be attributed to the fact that manos and metates served more roles — specifically ritual roles — than they did for the contemporary Maya. In this way, the average Classic Maya household would have needed to have more manos and metates on hand at any given time to fulfill ritual duties than the contemporary Maya household which predominantly uses manos and metates for food processing.

Furthermore, it should be pointed out that because the frequency of manos and metates functioned like social status among contemporary Maya and the Classic Maya, the frequency of manos and metates accumulated by households can be utilized roughly to gauge social status. Manos and metates in this sense can be seen as a kind of currency which, like all currency, has a symbolic importance attached to it and which can bestow increased status upon the household who wields it.

6.4.2 Interpreting the Trajectories of the States of the Exchange System

Because of the significance that mano and metate frequencies held for the Maya, the trajectories of the states of the exchange system would have represented the course of status through time (Figure 15). The closest analogy for status that exists in modern economics is wealth or "standard of living".

Standard of living is a concept that has had a long history of being debated by sociologists and economists, and there are various proposals as to how it should be defined (e.g. Cottam and Mangus 1942). For macroeconomists, "standard of living" is a term that is used to describe one's economic or material well-being. To be more specific, standard of living refers to income in modern economics, and it is determined by a few important factors according to Solow (1956), all of which affect the amount of capital people have; these factors are population growth, depreciation of capital, and savings rate. From an economic standpoint, these factors contribute to the economic growth of society and, therefore, the standard of living of people. That is, as population and depreciation rates rise there is less capital (i.e. wealth) to go around to every person or household. On the other hand, as savings rates increase there is more capital to go around. Societies with high standards of living, in other words, are those societies that have low rates of population growth and capital depreciation, and a high savings rate.

Although mano and metate frequency was an indication of status rather than wealth, mano and metate frequency probably would have had a similar effect on the Maya as the standard of living does on us today. In other words, mano and metate frequency would have functioned as a *marginal* standard of living at the communities, which the inhabitants would have experienced.[11]

[11]Standard of living in modern economies accounts for all of the exchange items (i.e. in

Therefore the trajectories of the states of the system would have held special meaning for the inhabitants of the Bladen Branch.

The inter-community distribution and accumulation of ground stone would have likely determined the relative sociopolitical standing of each of the communities. The inhabitants of the Lower Bladen sites would have been the primary storers of grinding implements followed distantly by the inhabitants of Muklebal Tzul and Ek Xux. This marginal standard of living, which would have been higher at the Lower Bladen sites and at Muklebal Tzul than at Ek Xux, would have arisen from supra-individual or macroeconomic processes and would have constituted a pattern to which all Bladen community members would have been attuned. In other words, the marginal standards of living at the communities would have constituted an emic social representation for the Bladen Maya inhabitants.

6.5 Conclusion: A Mathematical Model of Classic Maya Exchange

In this chapter, archaeological research is utilized to reconstruct an ancient Maya economic system in the Bladen region of the Maya Mountains. The main purpose of constructing this model is so that certain inferences may be drawn, which will facilitate in illuminating the issue of cognition in the next chapter. Whilst the model that I have constructed can be utilized to shed light on the political economic climate of the Bladen, I focus instead on how such systems as I have modeled are integral in forming representations in the human mind. In other words, in this thesis, the model constructed as the result of archaeological investigation is utilized as a means to an end, rather

GDP), not just one item as I have modeled here.

than an end in itself. This is because I am not particularly interested in answering questions about the Bladen Maya, so much as I am interested in using the Bladen exchange case study to illustrate how a social institutional process, such as the exchange of material goods, can be conceived of as a dynamical system.

Section 6.2 was dedicated to hypothesizing that Bladen exchange, which was examined in the last chapter, could be conceived of as a dynamical system. In Section 6.2, not only was it important to show that Bladen exchange had all of the properties that are commonly associated with dynamical systems (i.e. it had interrelated components and bounds), but it was critical to model Bladen exchange using mathematics that are used to describe dynamical systems, namely differential equations. The purpose of describing Bladen exchange mathematically was to capture the conceptual purity of the dynamical system provided that Bladen exchange constituted a dynamical system. The mathematical modeling of Bladen exchange also permitted me to reproduce Bladen exchange, which was the purpose of Section 6.4 and which was important for backing the proposal that Bladen exchange constituted a dynamical system.

Section 6.4 was dedicated to reproducing Bladen exchange through generating output from the mathematical model which described Bladen exchange. In order to do this, parameters for the mathematical model had to be approximated, and only then was output generated from the model. There are two ways in which a model generates output and that is through a mathematical analysis of the equations which model the phenomenon, or through simulation. Both means were utilized in this thesis. The mathematical analysis of the model of Bladen exchange was provided in *Appendix E*, and the results of simulating the model were represented in Figure 15. The results of the model were then compared with the ethnographic results provided by Hayden and Cannon (1984:70) for contemporary highland Maya. According to Hayden and Cannon, at the time they collected their data, highland Maya life in the communities that were studied had not significantly changed since before the Spanish Conquest, and so the data collected by them is suggested to be representative of the way in which Classic Maya would have lived. On the basis that Hayden and Cannon's inferences are correct, the ethnographic data was then used to assess the plausibility of the output generated by the model. As it turns out, the results from the model agreed with the ethnographic results, since the results from the model fell within the ranges provided by Hayden and Cannon (1984:70) for contemporary highland Maya. This, in effect, supported the notion that Bladen exchange can be considered to be a credible dynamical system. The mano and metate frequencies generated by the model exhibited slightly higher frequencies than the mean for the ethnographic data, however, this slight discrepancy can be attributed to the greater number of roles that manos and metates played in the Classic Maya period (i.e. ritual as well as domestic).

According to the archaeological and ethnographic, evidence frequencies of manos and metates were likely indicators of social status. In a way, the significance of manos and metates for the Classic Maya was similar to the significance of "standard of living" for us today in that both concepts have meaning for their societal members. The mathematical model which I constructed described the dynamical system in which frequencies of manos and metates at households changed through time. This dynamical system was important since it was within the dynamical system that cognition dwelled and, in fact, was generated.

A case in point, which will be carried through into the next chapter, are the trajectories of the states of the Bladen exchange system that converge on the stable equilibrium represented in Figure 15. Not only do these trajectories constitute a pattern of marginal standard of living for the inhabitants of the Bladen communities, but it likewise can be conceived of as constituting a cognitive representation for the Bladen inhabitants. In this way, the trajectories not only mean that the exchange system represented a stable economic system (approached an economic steady state), but they also mean that if we approach exchange from a different angle — that is if we conceive of the Bladen exchange system as a cognitive information processing system (i.e. like a neural network) — the exchange system's trajectories translate into representations to which the inhabitants of the Bladen communities were cognitively attuned. The support for conceiving of the Bladen exchange system as a *cognitive system* will be presented in the next chapter.

Part III

The Emergence of Supra-Individual Cognition

Chapter 7

Information Processing, Cognitive Systems, and Bladen Exchange

The objectives of this chapter are as follows:

- To explain that information processing capability arises in *all* dynamical systems and therefore in any social or economic system assessed as a credible dynamical system (see pages 315–316). For example, because the Bladen exchange system was shown to constitute a credible dynamical system, the Bladen exchange system can be conceived of as having information processing capability. *Information processing capability* is an essential characteristic of cognition and consists of the capabilities to store and retrieve information.

- To demonstrate that the Bladen exchange system constitutes a dynamical system *to which the inhabitants of the Bladen communities were attuned.* The implication of this demonstration is that exchange systems and indeed social systems that are shown to constitute credible dynamical systems may contain features that are perceptible to the people involved in these dynamical systems, thereby rendering these systems cognitive systems. *Cognitive systems* are the bases for generating cognition and therefore social systems assessed as cognitive systems will logically constitute generators of "supra-individual" cognition. In *supra-individual cognition*, information is built into "supra-individual memory" and thus stored for all of the individuals involved in the specific social system to experience as *representations.*

In the research discussed in Chapters 2 and 3, two cognitive capabilities were delineated and were argued to form what can be generally regarded as the basis of **cognition** (see Section 3.5.1). One is *perception* and the other is *information processing.* In addition to these two cognitive capabilities, a third cognitive capability, namely *executive control*, is also important in cognition. However, executive control is generally regarded as characteristic of information processing since they are both considered emergent properties of dynamical systems (see Section 7.2). I summarize the cognitive capabilities of perception and information processing below:

- **Perception**, in this thesis, is specifically defined as *attunement* to features — states or constraints — of a dynamical system. This extends Turvey and Carello's (1995) definition of perception in which perception is defined as attunement to only the invariant aspects of a dynamical system (i.e. constraints). However, it will be shown in this chapter that individuals can also be seen to be attuning to the varying aspects of a dynamical system (i.e. states). Moreover, it is the varying aspects of a dynamical system that permit the individual perceiver to process information supra-individually. In this more general notion of perception, a constraint *or a state* of the dynamical system is potential information for the perceiver.

When information is perceived, the information constitutes a *representation* in the brain of the individual. Because the process in which information is being perceived is in and of itself a dynamical system (e.g. the dynamical system that produces an image on your retina *and* neurally processes this image), a representation can be regarded as a feature of a dynamical system manifested as a pattern in the brain (i.e. a mental pattern). The basis upon which perception emerges is the *cognitive system*, which for pragmatic purposes is a dynamical system comprising the body, its associated nervous system (i.e. the individual), and the environment (van Gelder and Port 1995:3). *Environment* is a relative term and I use it to reflect the context in which an object is situated. For example, if the object of discussion is the individual, then the environment consists of the natural and social phenomena occurring outside of the individual. If the object of discussion is a neuron, then the environment comprises its linkages with other neurons in the nervous system.

- **Information processing** refers to processes governing how information is stored or retrieved. Though information processing is usually taken to be a product of computation, information processing is in its natural form as a dynamical system as I discussed in Chapter 3. As such, a *dynamical system* (rather than computation) will be considered to be the basis upon which information processing capability emerges. The dynamical system will also be the basis upon which executive control emerges, which means that information processing and executive control will generally co-occur.

In general, cognitive processes that are involved in manipulating representations within the nervous systems of many biological organisms (i.e. *learning* and *recalling*) can be conceived of as information processing. This is because representations *are* information, or patterns which are meaningful to a subject. For example, the act of *learning* representations can be explained (via information processing) as the process by which patterns are stored. Similarly, the act of *recalling* representations from memory can be explained (via information processing) as the process by which patterns are retrieved from storage. Here, *memory* is envisioned as a store in the brain for representations.

Information processing, however, is more than just a metaphor for cognition. The information processing paradigm has proved successful in explaining cognitive processes since the 1950s (see Section 2.3.2) and, as a result, is the main way in which scientists conceive of cognitive processes (Reisberg 1997).

7.1 Information Processing and Memory

Information processing consists of the capabilities to store patterns and retrieve patterns from storage, thereby generating patterns. **The functional phenomenon of information processing is attributable to *all* dynamical systems.**

7.1.1 Information Processing is a Fundamental Property of All Dynamical Systems

The concept of a system has been widely used in the sciences and, indeed, in archaeology (Clarke 1978; Flannery 1968). However, one of the most important properties of certain systems which has been overlooked by archaeologists and social scientists, in general, is the property of having a *memory* and hence information processing capability.

In Chapter 3, the focus was on dynamical systems and how cognitive systems *are* dynamical systems. The reverse need not be true, though all dynamical systems do have information processing capabilities and therefore can be thought of as having a rudimentary cognitive capacity.[1] Not all systems are dynamical, though most are. I will distinguish dynamical systems from non-dynamical systems or *static* systems next.

Static Systems

Static systems are systems that do not change with time. As such, a static system that is provided with an input source will simply respond instantaneously to the input.

In this way, the static system only constitutes a function of its present state. It does not rely on any previous states of the system since it has no history of the changes that took place in the system, and this is because the system is incapable of endogenous change. As a consequence of the lack of history of change, the system is said to be memory-less.

Figure 17 represents an electrical example of a memory-less system since it depicts a system with only an electrical source and a resistor. Here, the source, which could be a battery, generates a current. As the current crosses the resistor, which could represent a heat source of some kind, the voltage drops. With only a resistor, the energy in the system dissipates. Energy, regarded by most system dynamicists to be synonymous with information,

[1]Still, it takes a subject's *attunement* to a dynamical system in order for it to be considered a cognitive system as I discuss in Section 7.3.

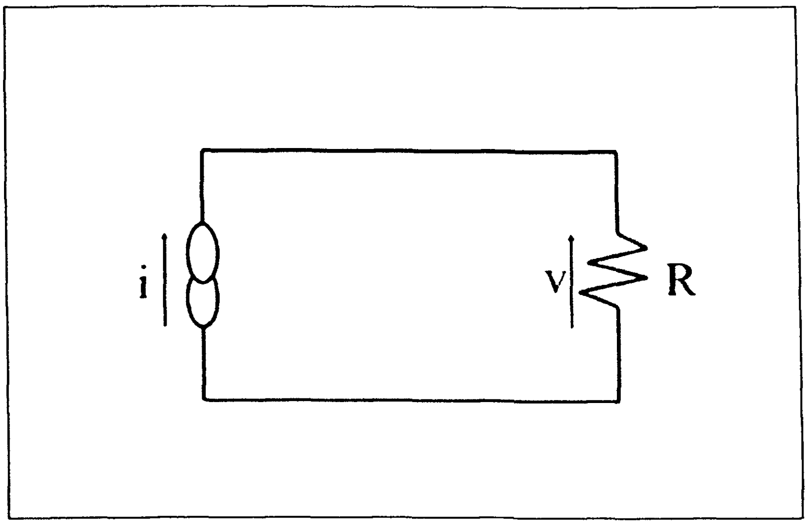

Figure 17: In this idealized electrical system, the voltage (v) across the resistor (R) responds instantaneously to input or current (i) generated by a source. This static system therefore constitutes a memory-less system.

as Wellstead (1979:14) notes, is released by the system and not recovered.

The main reason that the information is non-recoverable in this system is that the system has no storage component. The mathematical description of this system according to Ohm's Law is simply:

$$i = \frac{v}{R},$$

which means that the voltage across the resistor (R) responds instantaneously to the current (i) supplied by the battery (v). A battery, which can only supply so much voltage to the system will eventually fail as an electrical source. Consequently, the entire system will eventually fail because the system is entirely dependent on the battery.

Dynamical Systems

Dynamical systems, as I have already discussed in Chapter 3 are systems that *do* change with time. As such, a dynamical system that is provided with an input source will respond to the whatever is input into the system along with whatever endogenous changes have occurred in the system through time.

In a dynamical system, the dynamical system's present state constitutes a function of the dynamical system's past states due to feedback in the system. Therefore, a dynamical system depends on the previous states as well as on the present states of the system. That is, the present states can be seen to be storing any of the previous states. Therefore, a dynamical system has a history of the changes that took place to it throughout the system's development. As a result, a dynamical system is said to have a memory, such that the information being stored in the system's memory constitutes the states of the dynamical system. As I discussed in Section 2.2.2, an example of a system that is dynamical and hence has a memory is a recurrent network.

Figure 18 represents an electrical example of a system with a memory. It depicts a system with an electrical source, a resistor, and a capacitor. The source, which is a battery, generates a current. As the current crosses the resistor (e.g. a heat source) and the capacitor, the voltage drops. However, with the capacitor, information is stored.

Information, therefore, is recoverable in this system since it has a storage component. The mathematical model of this system, which describes the total current across the circuit, is:

$$C\frac{dv}{dt} + \frac{v}{R} = i.$$

What this model tells us is that the voltages across the resistor (R) and across the capacitor (C) respond to the current (i) supplied by the battery. The capacitor in this case protects the system from failure — the current crossing the capacitor being defined by $C\frac{dv}{dt}$. By including differentiation (or integration if we rewrite the system with respect to voltage [i.e. $\frac{1}{C}\int_0^t i\ dt + Ri = v$]) and a constraint represented by the parameter C, we get a system with memory that stores information. Note that we can represent the memory of this information clearly in the equation: $v_c(t) = \frac{1}{C}\int_0^t i\ dt$. This equation encapsulates the entire voltage history of the capacitor for all t starting with zero.

I used an electrical system to illustrate information storage but all dynamical systems have this information processing capability. See Shearer, Kulakowski, and Gardner (1997:3-5) and Wellstead (1979) for a discussion of this information/energy capacity in other dynamical systems besides electrical systems. Also, refer *Appendix F* to see how the Bladen exchange system can be seen to be storing information.

Information storage has been shown to be a capability of all dynamical systems, but how about information retrieval?

Being able to store information (i.e. have a memory) implies that the information being stored is recoverable. If information is recoverable, it means that the information is retrievable, not in the sense that information is taken away from the system but in the sense that information can be accessed (i.e. perceived by another information processing system). Thus, information retrieval goes hand-in-hand with information storage. They are not dichotomous processes but complementary processes, which are both capabilities of all dynamical systems.

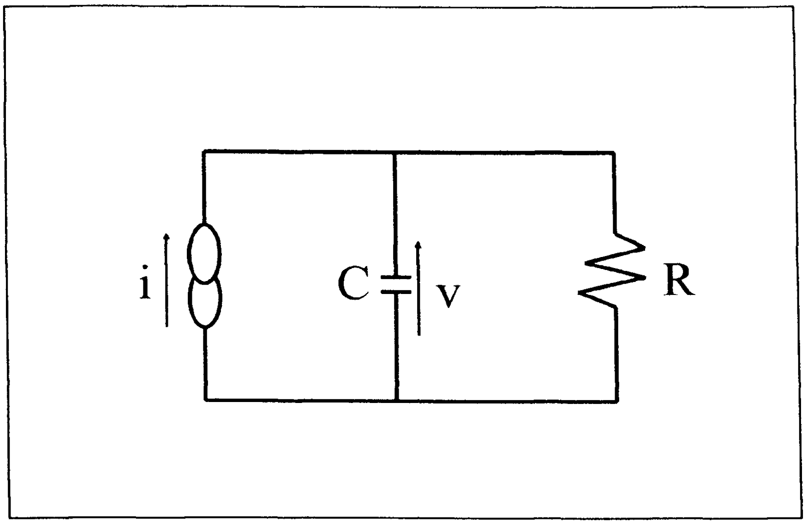

Figure 18: In this electrical system, the voltage (v) across the resistor (R) responds to input or current (i) generated by a source as well as its history of past states which are stored in the capacitor (C). This dynamical system therefore constitutes a system with a memory.

Discussion of Information Processing in Dynamical Systems

Does this mean that systems need only to be dynamical to process information? Theoretically, "yes". Being dynamical is a *sufficient* condition for a system to qualify as having information processing capacity. This is because information processing is a property that does not rely on a physical or chemical process; that is, the physical or chemical substrate of a system does not influence information processing capability. (Note that what Chalmers [1996] [see Section 3.4.2] refers to as a *functional organization* for generating cognition is essentially a dynamical system.) So long as systems are dynamical and therefore capable of being described by differential equations, they will have information processing capability. This can most clearly be demonstrated in the Bladen exchange system. Because information processing capability has been shown to be a property of all dynamical systems, and because Bladen inter-community exchange can be seen to constitute a dynamical system, Bladen inter-community exchange can also be conceived of as having information processing capability. A more formal discussion of the information processing capability of Bladen exchange is presented in *Appendix F.*

Does this mean that dynamical systems do not need to be in the form of a network, or more precisely in the form of a parallel distributed network (PDN), in order to process information? Again, "yes". However, there is something to be said for dynamical systems *that have a parallel distributed architecture.* PDNs have the capacity for being autonomous, self-organizing systems, as I have described in Section 3.2.2. So, in addition to being able to process information, a dynamic PDN could be conceived of as a dynamical system with a rudimentary domain-general consciousness, not unlike a brain, in so far as the system maintains an independence from other dynamical systems and controls its own functioning in a distributed fashion without a specific executive control center.[2]

7.1.2 Summarizing How Information Is Processed in a Dynamical System

To summarize, the term "information" refers to a pattern in the values of the states of a dynamical system. This *pattern* can either be the value of

[2]Although this does not figure directly into this discussion, another important characteristic of PDNs is that they are very good at approximating other dynamical systems. They are able to take the form of almost any kind of dynamical system, and this interesting property will be mentioned again in the next chapter as it plays a role in how individual brains *internalize* representations.

a dynamical system's state with respect to time (i.e. a trajectory of the dynamical system), or for dynamical systems with multiple states, the pattern can be the values of a dynamical system's states with respect to each other. Hence, information processing constitutes the processes by which a dynamical system's state patterns are stored and retrieved, and a dynamical system that processes information is one that accepts and stores state patterns, which subsequently can be retrieved.

Information is stored in a dynamical system by virtue of a reverse feedback loop which is characteristic of all dynamical systems. This reverse feedback loop stores past state values by continuously "recycling" the past state values and redirecting them back into the system. In this way, every present state value is some function of the system's past state values. That is, any past state value can be seen to be stored in the present state value of a dynamical system. As a result, the dynamical system is said to have memory.

Retrieval of this information occurs continuously in the dynamical system as the dynamical system is continuously utilizing its past state values to generate the present state value of the system. Thus, every dynamical system can be seen to be retrieving information for its own operation. Dynamical systems can also retrieve information from each other through attunement. That is, one dynamical system can retrieve information from another dynamical system as long as the former dynamical system is perceiving the latter dynamical system's states. The process by which this occurs is called *internalization* and it will be discussed in more detail in the next chapter.

7.2 The Independence of Information Processing

Since information processing capability is shown to be a property of all dynamical systems, such as the Bladen inter-community exchange system, a natural and perhaps unsettling question that arises is: Is an inter-community exchange network, such as the Bladen system, independent in the sense that it can autonomously control its own information processing? And if it is independent, where does the individual with his or her brain and its information processing capability fit into the picture?

The answer to the first question regarding executive control will be discussed in this section. The answer to second question concerning the individual's role will become apparent in the next chapter.

7.2.1 Executive Control of Dynamical Systems

In theories that deal with the issue of power, we often attribute power to an individual (e.g. agency or action theory). However, if I were to attempt to discern executive control in a mental system in the same way a sociologist would look for power in a social system, certain problems would arise. This is because attributing control solely to an individual — who consists of a nervous system and body — does not explain how the nervous system processes information. The neuron is below the level of the "individual" and therefore out of the individual's complete or conscious control. Nonetheless, seeking to distinguish executive control in a social dynamical system can be accomplished in the manner in which power is sought. In other words, seeking executive control in social dynamical systems is much simpler than looking for executive control in mental dynamical systems, since at the level of "society" or "community", the individual *can* be conceived of as playing the role of executive controller in social information processing. This is essentially what action theory is about (Giddens 1979).

But can we attribute control *solely* to the individual? If we accept that the factors for determining how much consciousness we grant a system consist of the analog nature of dynamical systems taken together with the distributed property of networks (Donald 2001), then consciousness, at least in its rudimentary form, should carry over to social dynamical systems as well as inter-neuronal dynamical systems. According to Donald and other connectionists (e.g. Reisberg 1997), executive control, or consciousness, is a distributed phenomenon throughout the network and it only emerges when all of the nodes in the network are working as a system — in our case, a social system. Therefore, if we concur with the connectionists, we cannot attribute executive control in a society solely to the individual because control also lies with society.

To gain further insight into the executive control of social dynamical systems and into the independence of social dynamical systems from other dynamical systems, I will utilize what is known of executive control in the brain (recall Section 3.2.2), and logically extend it to other dynamical systems including social dynamical systems.

7.2.2 Connectionism: The Seat of Executive Control Revisited

If we attempt to explain how information processing capability in the brain is controlled, we run into certain difficulties. For instance, a quick response to the question: "What controls information processing in the brain?" might consist of: "Information processing in the brain is controlled by *us* as individuals. If *I* individually need or want to learn a pattern, I spend time and effort on storing the pattern into memory so that I can recall it later."

The problem with this explanation of control, however, is that we introduce an abstract controlling mechanism — namely "I" — which needs to be accounted for. In other words, who is this "I" who has the capability of controlling neural networks in the brain?

There are different theories surrounding this ulterior intelligence controlling mechanism, which "directs" us to learn something (Reisberg 1997:292-299):

- One theory is that a *homunculus* guides us in learning and thinking. A *homunculus* used to be a term utilized to describe a little man, but it has been adopted by cognitive scientists and philosophers to refer to a conscious, *indivisible* controlling mechanism in a specific locale within the brain (i.e. the *ego*).

- An alternative explanation, which is advocated in connectionism and which I discussed in Section 3.2.2, is that no "master planner" is required, since control of information processing resides throughout the dynamical system, distributed throughout the entire network (Reisberg 1997:295-299).

The connectionist view concurs with current cognitive research about where the seat of consciousness resides. That is, consciousness is usually regarded to be *domain general*. Based on the neuro-physiological data accumulated so far, consciousness does not appear to be the objective of some particular module in the brain, but rather a phenomenon distributed throughout the brain (Donald 2001:37,114). Thus, it would seem that control is a distributed phenomenon in which the whole is considerably greater than the sum of its parts. (Although I am specifically concerned about the connectionist view of executive control in this chapter, this is not to say that in a multi-layer world that the homuncular concept does not have value. In fact, I believe it does have value and I discuss the role it plays in developing a comprehensive understanding of cognition below and in Chapter 8.)

The connectionist view of executive control begins with notion that information processing in the brain arises from a network of very simple interconnected components. These components, or neurons, in and of themselves do not amount to anything special, but when taken together they constitute a network with the potential to self-organize and maintain some degree of control over functioning. In the case of human brains, with such a large number of neurons located in a small body mass,[3] it should not be surprising that humans have such a high degree of control relative to other animals (Donald 2001:105). This same phenomenon of distributed control can be carried over to other dynamical systems with network architectures, such as artificial neural networks and even certain social systems (e.g. exchange networks).

Executive Control in Artificial Neural Networks

In artificial neural processing, the issue of control should be explainable through connectionism just as it was for biological neural networks.

It could be inferred that some philosophers, such as Chalmers (1996), believe that computers are conscious of their purposes in processing, whereas others such as Searle (1990) are skeptical of such claims. If being conscious is having a certain degree of control over certain faculties, and if this in turn

[3]The premise here is that less cognitive effort is expended controlling a small body than a large body, which means that cognition can be put to other uses (i.e. controlling things outside of the one's body).

is the ability of a computer to choose to stop one program and to run a completely different program from the one that was run before — in other words, to adjust — then it is certain that computers have achieved consciousness. We see this capability in computer games such as chess, where one subprogram designed for a particular strategy switches to another subprogram that effects another strategy.

Hence, I would agree with Chalmers that certain capacities of AI constitute a consciousness of sorts, but to what degree is unclear. Artificial neural networks have a certain degree of control over what gets processed when and where; that is, they exhibit features that allow them control over some of their own capabilities. However, in addition to this self-organizational capability, which artificial neural networks seem to have, artificial neural networks are also subject to human control. That is, we function as homunculi in that we design the computers and we use computers for processing what we want them to process. For instance, if we want to write a story, we can use a word processing program, and if we want to solve an equation, we can use a numerical modeling program. In this way control can be said to be distributed not only within the ranks of networks but between these ranks. In the case of artificial neural networks, for instance, control is distributed within and between our biological neural networks and the artificial neural networks. This was precisely Clark and Chalmers' (1998) point, as I discussed in Section 3.4.3.

Executive Control in Credible Social Dynamical Systems

As was demonstrated with regard to the Bladen exchange system (see *Appendix F*), information processing can be conceived of as occurring at a social level distinct from the individual brain and distinct from any artificial means that are used to process information. I refer to this sort of information processing which can be seen to be manifesting itself at the social level as *social processing*. Unlike the processing which occurs in natural and artificial neural networks, the processing of social systems is more difficult to characterize because it is unclear whether the social system in question can be conceived of as a credible dynamical system. The social system in question must first be assessed through mathematical modeling and analysis before it can be conceived of as a dynamical system, which in turn will determine whether the system has information processing capability.

The reason why individuals are unaware that social systems process information may be that the individual views society from the perspective of a participant, from the inside of emergent supra-individual cognition. If society is viewed from the perspective of a participant, this is not unlike awareness of total brain function or "thinking" from the perspective of a neuron. A neuron does not function in terms of awareness of the brain as an organ of "thought" any more than individuals are aware of information processing at the level of society. It is no surprise, therefore, that many see society as nothing other than something that comprises us (the individual) and which is our creation.

If the property responsible for generating executive control is inherent in dynamical parallel distributed networks (PDN) as connectionists propose, then this implies that executive control can also be seen to be present in credible social and economic dynamical systems and can be seen to be distributed over the different nodes of the interactive network whatever these nodes may be. This distribution of control over the nodes endows the brain some independence from the neuron, and the credible social or economic system some independence from the individual.

This is consistent with Durkheim's view of society. Individuals of course make up society, and individuals in a group could be examined on a physiological basis to explain some social phenomena, but the definition of a group of individuals does not constitute society. As I discussed in Section 3.4.1, "society" has a historical meaning that goes beyond subsuming a group of individuals (Durkheim 1933). A society includes individuals who hold sentiments in common. These sentiments supercede individuals, akin to Durkheim's "collective conscience" (1933:79-81).

However, does this mean that we as individuals are unaware of the social information that is processed and that we have no role in controlling the information? I will explain in the next section that individuals acquire social representations, such as "standard of living", without having to obtain these representations through discourse but instead by obtaining representations through experiencing certain features of the social or economic dynamical system. Thus, social representations do have a direct impact on us individually since they can affect the way we as individuals process information.

Conversely, our mental representations, through actions, can effect changes in how representations are socially processed; therefore, we have a certain control over the kinds of social representations that we are presented with individually. In this latter regard, we function a little like *homunculi* for social dynamical systems as well as for artificial dynamical systems.

What this means is that, like AI or any other artificial mnemonic device we design and use, social dynamical systems (e.g. exchange networks) can be seen as interacting with inter-neuronal dynamical systems (i.e. individual brains). As well as maintaining the social dynamical system, individuals can also be seen as being able to update the social dynamical system in which they live. Individuals, therefore, potentially can make changes to the social

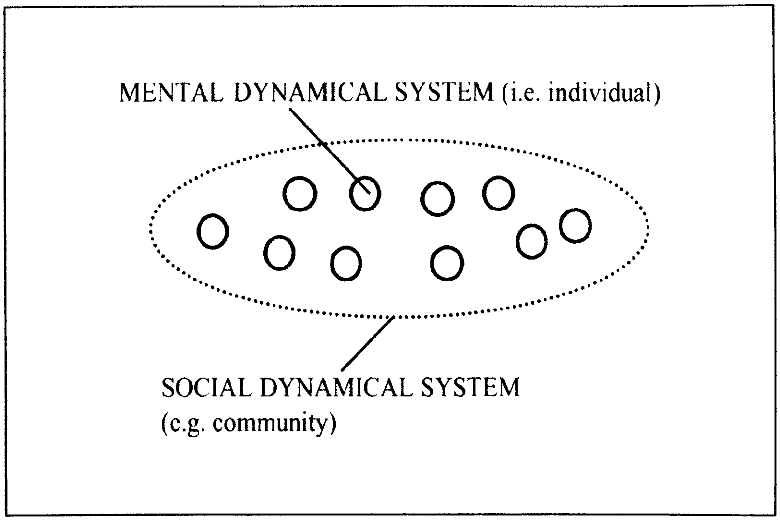

Figure 19: In this idealistic diagram, inter-neuronal dynamical systems (represented by the solid circles) and the social dynamical system (represented by the dotted oval) do not affect each other. They do, however, each process information, such that each dynamical system generates its own representations independently.

representations to which they are attuned. How mental and social dynamical systems can be conceived of as interacting with each other will be discussed more thoroughly in the next chapter.

7.3 The Cognitive System

Perception, unlike information processing, is a phenomenon which, above all, requires an individual or subject to do the perceiving or the experiencing. To explain how cognition or, more specifically, how perception arises, one needs only to show that the process that leads to perception constitutes a perceptible dynamical system (i.e. a cognitive system).

Theoretically, a **cognitive system** is a dynamical system that is perceived by any information processor (see Section 3.5.1), but for the purposes of the thesis this information processor will be considered to be a human brain, since the subjects of analysis in my thesis are humans. The features of the dynamical system which humans can perceive are the constraints or the states of the dynamical system. Perceptibility of some feature of a dynamical system is important to include in any definition of a cognitive system and it has been advocated by the van Gelder camp as well as Clark and Chalmers (1998) and Donald (1991). That is, cognitive systems are first and foremost systems that are in some way coupled with the cognition of a subject.

7.3.1 Cognitive Awareness of Features of the Dynamical System

The first requirement for a dynamical system to qualify as a cognitive system is its ability to be perceived by a subject. In the case of humans, humans must be attuned to certain aspects of the dynamical system, which I propose can be referred to as *cognitive features.* A dynamical system with this characteristic is called a *cognitive system.*

Cognitive Features

I propose that a cognitive feature is any feature in the physical or social environment that is perceptible. What this means is that a cognitive feature exists in two places: it exists outside of one's brain in the physical or social environment, and it exists inside of one's brain, within the neural substrate.

- The fact that a cognitive feature exists outside of one's brain, as well as inside, should be intuitively clear. It can be a chair, a city, a moiety, a friend, a home, a house, and practically anything. Without a counterpart in the brain there is no cognitive feature, only an *environmental* *feature.* An environmental feature exists regardless of whether or not it constitutes a cognitive feature.

- A feature in the environment which can also exist within an individual's brain does so by manifesting itself as a *pattern* in the neural substrate of the brain of the individual. That is, there are select neurons or groups of neurons in the brain that when activated form a pattern of the environmental feature in the brain. The pattern formed of an environmental feature in the brain is not a figment of the imagination, but it stems from specific activated neural sectors of the brain.

An important point to realize is that a cognitive feature for an individual exists in material form both in the environment, and within the neural substrate of an individual's brain. In the environment, the cognitive feature constitutes some object or action, and in the brain it constitutes a set of firing neurons. Whereas this might satisfy the material definition of a cognitive feature, this means that from a phenomenological perspective, a cognitive feature is not only a feature of the environment nor is it solely a pattern of activated neurons, but it also constitutes a *representation*, and hence a feature of the mind. In the view that I advocate, the mind has no established substrate, since it can be conceived of as manifesting itself either in the environment or in the brain. Similarly, representations can be seen to form in the brain or in the environment, but since they also constitute meaningful information for the brain, they are recognized as a product of the individual's mind.

Another important aspect of cognitive features is that they *can* move or change through time. This is because environmental features can change through time and their changes through time are governed by dynamical systems. For example, objects move, increase in quantity, decrease in quantity, change color, get larger, or get smaller. Similarly, actions grow in intensity, decrease in intensity, or lead to other actions. As such, a change to an environmental feature will have a corresponding representational change in the brain and mind of the individual as long as the individual is attuned to the environmental feature. In this thesis I am strictly concerned with environmental features that are governed by dynamical systems, particularly those features which constitute the states of dynamical systems. This has important implications for anyone interested in studying representations, such as an archaeologist.

Although an observer (e.g. an archaeologist) does not know what will happen to a representation or what form a representation will take in the brain at some later time, the observer can infer these representational changes by studying the dynamical system that is moving or transforming the environmental feature, as long as the environmental feature is a cognitive feature. Of course, the dynamical system will only be approximated within the brain of the individual, but it will play a fundamental role outside of the brain in affecting the environmental feature which will in turn affect the representation forming in the brain of the individual, provided that the individual is attuned to an environmental feature of the dynamical system. Therefore, in order to get at how representations transform themselves through time within the brain and mind of the individual, it is absolutely essential to infer representational transformation via the dynamical system in the environment.

Because dynamical systems determine where an environmental feature will be at any moment of time, and provided that the environmental feature is perceived by the individual, then the environmental feature will have a representational correspondence in the brain of the individual. In this way, when the dynamical system acts on a feature in the environment, it also acts on the representation of the feature within the individual's brain and mind.

Cognitive Systems

A cognitive system is a dynamical system with environmental features to which an individual is attuned (i.e. environmental features with representational counterparts in the brain and mind of the individual). That is, a cognitive system is a dynamical system which exhibits cognitive features.

The idea that cognitive systems must be able to be perceived should be clear. Environmental features of the dynamical system, such as the constraints on the system described by the parameters of the model or the states of the dynamical system described by the variables in the model, must be perceived by the subject's brain in order to constitute a cognitive system.

A perfect example of a cognitive system in the brain is the neural dynamical system defined by the Additive Short-Term Memory (STM) and Passive Delay Long-Term Memory (LTM) Equations (i.e. Equations 3.12-3.13):

$$\frac{dx_i}{dt} = -A_i(x_i(t))x_i(t) + \sum_{k=1;k\neq i}^{n} b_{ki} f[x_k(t-\tau_{ki})-\theta_k] Z_{ki}(t) - \sum_{k=1;k\neq i}^{n} c_{ki} f[x_k(t-\tau_{ki})-\theta_k] + I_i(t)$$

$$\frac{dZ_{ij}}{dt} = -B_{ij}(Z_{ij}(t))Z_{ij}(t) + d_{ij} f[x_i(t-\tau_{ij}) - \Gamma_i][x_j(t)]^{+}.$$

These equations describe the mental processes of learning and recalling. The states in these systems are the STM trace represented by the variable $x_i(t)$ and the LTM trace represented by the variable $Z_{ij}(t)$.

Whereas the STM trace is perceptible, the LTM trace is not perceptible (Harvey 1994:176-177). As a result we are only aware of the STM traces which form the representations (e.g. perceptions, feelings, images, and impressions) that manifest themselves in our brain. We are not aware of the LTM traces that provide the basis for generating the STM traces.

What this means is that the LTM dynamical system *by itself* is not a cognitive system since it is imperceptible to the subject. The STM dynamical system, on the other hand, does constitute a cognitive system since it is perceptible to the subject. Taken together this implies that the LTM dynamical system coupled with the STM dynamical system, described by Equations 3.12-3.13, also constitutes a cognitive system. It is the contribution from the STM dynamical system, however, which makes the coupled system a cognitive system, since the STM dynamical system is the only system in the union of dynamical systems that is perceptible.

This discussion of the STM and LTM equations is meant to show that the neural dynamical approach is compatible with a cognitive systems approach and that a neural dynamical system can be seen as a particular kind of cognitive system. What the notion of cognitive systems affords neural dynamics is a more general model within which to situate neural dynamical systems.

7.3.2 What Does and Does Not Constitute a Cognitive System

Whether or not a dynamical system is a perceptible system depends on the *subject* doing the perceiving. A dynamical system that is a cognitive system for one individual may not be a cognitive system for somebody else. An individual accelerating out of a garage in France will undoubtedly perceive the dynamical system comprising the accelerating car. However, an individual in China, for example, will not perceive the dynamical system of the car driving in France.

Another important point to make is that not all dynamical systems are cognitive systems. A tree falling in a forest with nobody around to witness it constitutes a dynamical system, but it by no means constitutes a cognitive system since no one is aware of the tree falling. Therefore, cognitive systems comprise a subset of all dynamical systems and hence do not exhaust all dynamical systems in the universe. The presumption that there are dynamical systems that are not necessarily perceptible implies that though cognitive systems are subjective (i.e. require a subject to witness the dynamical system), there exists an objective reality where there are dynamical systems in motion of which we are never aware.

The approach taken in this thesis is that there is a reality outside of our field of perception. The reason for taking this stance is that it is difficult to deny that there are dynamical systems in progress which we do not perceive, when we are aware of these dynamical systems' after-effects. For example, one explanation for a tree lying on the ground in a forest is that there was a dynamical system in which gravity took its toll on the tree. Just because we do not perceive the dynamical system that brought the tree down does not mean that the dynamical system that brought the tree down never existed. It just means that it did not exist for a subject. (One could argue that the dynamical system that brought the tree down is a cognitive system since the dynamical system that brought the tree down is still in progress [i.e. perhaps one could argue that gravity is pushing the resting tree into the ground], but this is an entirely different argument than the argument that all dynamical systems are cognitive systems.)

The above discussion brings up another point. How long does it take for a dynamical system to reach completion (e.g. stabilize)? Potentially, a dynamical system can go on forever. Still, this does not mean that a dynamical system that goes on forever will ever be perceived by someone, and this goes back to the point made above, which is that not all dynamical systems are perceptible.

7.3.3 Epistemic Properties of Cognitive Systems

When an individual is attuned to a dynamical system, the dynamical system can serve a purpose by facilitating or enhancing, either physiologically or cognitively, an individual's well-being (e.g. helps problem solving).[4]

Because cognitive systems are perceptible to the subject, cognitive systems relay information that is processed by the subject. After processing, information can then be utilized by the subject to advance his or her position (i.e. well-being). The subject receives information from the dynamical system and either acts according to the information provided, or processes the information and decides what to do or how to act based on this information.

Cognitive systems that are coextensive with the individual and physical or social environment can facilitate the individual in several ways. One way that a cognitive system can facilitate the individual is by enhancing the individual's cognitive capabilities. An example of such a cognitive system is an epistemic action. In Section 3.4.3, I explained that an *epistemic action* is an action, usually taken to be intentional, which improves an individual's biological cognitive capability (Kirsh and Maglio 1994); that is to say, it is an action which *externalizes* the learning process, thereby facilitating the subject in processing information more efficiently.

By enhancing cognitive processes through being part of a dynamical system, the individual gains knowledge and can improve his/her chances of adjusting to the environment. For example, suppose someone falls off a chair or from a tree for the first time. Then, it is through that person's unfortunate involvement in the dynamical system (i.e. perhaps that person's attunement

[4]This point has been advocated by the cognitive evolutionist school of thought (e.g. Donald [1991]) and Clark and Chalmers (1998), Kirsh and Maglio (1994)). They see the basis of cognition to be an evolutionary adaptation.

to his/her momentum at impact with the earth's surface) that one learns that it is best not to fall because of the physiologically damaging consequences upon hitting the ground. In this way, by being attuned to a dynamical system, one not only learns about falling,[5] but one learns that one should not fall and risk hurting oneself in the future. More importantly, being attuned to supra-individual dynamical systems frees the brain to conduct other cognitive tasks.

Being attuned to dynamical systems that exist supra-individually enhances one's individual biological cognitive capacities. In so doing, cognitive systems that link the individual with the environment can potentially help that individual survive in the environment.

7.4 The Bladen Exchange System as a Cognitive System

According to the definition of "cognitive system" that I described at the beginning of this chapter, which is based on the definition provided by van Gelder and others (see the beginning of this chapter), it is possible to conceive of the Bladen exchange system as constituting a *cognitive system.*

A cognitive system is a dynamical system that has some feature which is perceptible by a subject. In other words, a cognitive system is a dynamical system such that the constraints or the states of the dynamical system are being perceived. By proposing that the Bladen exchange system was a

[5]Falling is considered by evolutionary psychologists to constitute innate knowledge contained in a naïve physics module. While this might be true, it is unlikely that such innate knowledge would contain information related to the *experience* of falling and the *pain* associated with hitting the ground.

cognitive system, I am suggesting that an environmental feature of the dynamical system described by Equations 6.7-6.9 constituted a feature which was perceived by the Classic Maya of the Bladen region.

The fact that the Bladen Maya can be seen to have been attuned to the Bladen exchange system is supported by the archaeological, geological, and ethnographic data. Some features of the Bladen exchange system to which the Bladen Maya can be seen to have been attuned are discussed below:

1. The three economic centers of Muklebal Tzul, Ek Xux, and the Lower Bladen sites had corresponding representations in the minds of people living in the Bladen area.

Evidence gathered from topography, settlement pattern analyses, and excavation suggests the the Bladen centers were *independent.* By independent I mean that each center was to some extent politically autonomous (discussed in Section 5.4.3). Each center was also economically autonomous in that each had its own local rock resources well suited for the manufacturing of manos and metates.

The Bladen centers and their associated resource and sustaining areas are well defined topographically and geologically. The factor that most clearly delineates the boundaries of the centers' associated resource and sustaining area is rock type. Each center is situated in a valley or zone containing a distinctive rock type that was exploited. For the Muklebal valley it is bedded limestone, for the Ek Xux valley it is highly silicified volcanic rock, and for the Lower Bladen valleys it is volcaniclastic rock.

The assertion that the boundaries of the centers' political realms are also to some extent shaped by rock types is supported by settlement features within these zones. In each rock type zone there exists a site with stelae, which are defining features in politically autonomous centers. These politically autonomous centers would have held a political as well as economic claim to their associated zones. (Recall Section 5.4.3 where it was discussed that the communities' political markers coincide with the distribution of rock types that were exploited at the communities). What this means is that each center can be regarded as a *cognitive feature*, with each center delimited by what could best be termed a *cognitive boundary*. A cognitive boundary is a cognitive feature that circumscribes some entity in the physical environment and which, because of its sheer formidability or distinction, cannot escape being perceived by the analyst (etically) or by the people the analyst is studying (emically) (Dunham 1990:110-123). In the case of the Bladen, the three rock type zones would have constituted cognitive boundaries of the Bladen centers.

2. The frequency of manos and metates at households at the three economic centers of Muklebal Tzul, Ek Xux, and the Lower Bladen sites had corresponding representations in the minds of people living in the Bladen area.

Ethnographic, ethnohistoric, and archaeological data indicate that the frequency of manos and metates in households were an important feature of Classic Maya life, and to which the Maya would have paid attention (see pages 299–302 for a discussion on the importance of frequency).

Though manos and metates were used in domestic contexts, they were also utilized in ritual contexts. They were necessary to fulfill certain obligations and as such were utilized in rituals associated with dedications, terminations, burials, and for cementing social bonds between households. Because of the important role that manos and metates played in domestic and ritual realms, the frequency of manos and metates would have been an indication of one's wealth and obligations and therefore constituted a measure of status as I discuss on pages 299–300.

In other words, the Bladen Maya can be seen to have been attuned to the states of the exchange system I modeled using Equations 6.7-6.9 (below):

$$\frac{dx_1(t)}{dt} = -Ax_1(t) + [k_{11} + k_{1I}]f(x_1) + k_{12}f(x_2) + k_{13}f(x_3)$$

$$\frac{dx_2(t)}{dt} = -Ax_2(t) + k_{21}f(x_1) + [k_{22} + k_{2I}]f(x_2) + k_{23}f(x_3)$$

$$\frac{dx_3(t)}{dt} = -Ax_3(t) + k_{32}f(x_2) + [k_{33} + k_{3I}]f(x_3).$$

Therefore, the Bladen exchange system, described by Equations 6.7-6.9, constitutes a cognitive system. What this means is that from the viewpoint of the archaeologist, the Classic Maya living in the Bladen can be seen to be attuned to the variables of the equations describing the states of the exchange system for each community (i.e. $x_1(t)$, $x_2(t)$, and $x_3(t)$).

7.5 Cognitive Implications of Classic Maya Ground Stone Exchange in the Bladen

This section discusses the implications that the Bladen exchange system has for cognitive systems and cognitive studies, in general.

7.5.1 What the Bladen Exchange Case Study Can Tell Us About Cognitive Systems

The economic model constructed for Bladen exchange raises important issues for cognitive systems. It suggests that not only can an individual be attuned to a dynamical system — thereby forming a cognitive system — but several individuals can be attuned to a dynamical system simultaneously, and in so doing form a cognitive system.

Cognitive systems to which several individuals are attuned will be called **supra-individual cognitive systems**. An example of a supra-individual cognitive system is the Bladen exchange system because every individual who actively participated in the Bladen exchange system would have perceived the representational standard of living with respect to manos and metates. Those cognitive systems to which only one individual is attuned will be called **individual cognitive systems**. Some examples of the an individual cognitive system is Turvey and Carello's (1995) person wielding a tool (Section 3.4.4), Clark and Chalmers' (1998) hypothetical situation of a person playing a computer game (Section 3.4.3), or Additive Short-Term Memory (modeled by Equation 3.14 in Section 3.3).

The fact both individual and supra-individual cognitive systems can be seen to exist means that cognition can be conceived of as comprising layer upon layer of cognitive systems. In this view, each individual has his/her own cognitive system and subsuming these individual cognitive systems are supra-individual cognitive systems to which several individuals are connected.

The notion that cognitive systems overlap can be referred to as the *nested cognitive view*. A cognitive system in this model can be seen as manifesting itself within the brain at the inter-neuronal level or, as I have shown with the Bladen case study, in larger nodal units, such as among communities. Cognition can be conceived of as existing at other levels in between these two layers and possibly beyond the inter-community level as well. Maris and te Boekhorst's (1996) work and Kennedy's (1998) research have demonstrated that a form of cognition which can be referred to as *social* cognition can manifest itself inter-individually. This view was supported in Sections 2.4.3 and 2.4.2, respectively. I will now discuss some implications of the nested cognitive view.

7.5.2 The Implications of Distinct Cognitive Systems for Representations

Whereas there may be some debate about the details of what defines an idea or a belief, both can be regarded as *information* (van Dijk 1998:21). Consistent with the terminology in cognitive science (e.g. Hinton, McClelland, and Rumelhart 1986:77-109), I will usually refer to ideas and beliefs as *representations*, which are, in turn, *patterns* that arise from the states of a dynamical system. Turvey and Carello's (1995) work has shown that in addition to arising from the states of a dynamical system, representations can arise from any perceptible feature of the dynamical system including the constraints of the dynamical system. Representations, wherever they may appear, are always associated with the processes that create them, and therefore representations are linked with cognitive systems.

As I have just discussed, since cognitive systems need not be restricted to a single brain, neither do representations need to be restricted to a single brain. A representation can arise within the brain of an individual as a perception (i.e. an impression in the mind of the individual) of a color; or a representation could manifest itself within a society as a meaning (i.e. an impression in the minds of multiple individuals) associated with a sign. In other words, a representation can manifest itself only for an individual, called a *mental representation*, or it can manifest itself for many individuals at once, called a *social representation*; and whether a representation is only perceived by an individual or is perceived by a group of individuals depends on the level at which the cognitive system is operating. Clearly, a color can be a social representation as well as a mental representation, as long as the cognitive system that is responsible for the representation is manifesting itself supra-individually. Thus, it is the level at which cognitive processes are being engaged to produce the representation that is the factor determining the type of representation produced — mental or social.

7.5.3 Explaining the Standard of Living Representation

In the last chapter, I constructed a macroeconomic model that was used to describe the exchange of ground stone implements among communities in the Bladen region of the Maya Mountains. The model simulates what the economic growth of the communities would have looked like with respect to ground stone tools. This can be seen as ascertaining the "marginal" standard of living in the Bladen region at all three centers participating in the exchange of ground stone tools. However, standard of living is an interesting phenomenon because, on one hand, it corresponds to the amount of capital that has accrued in an economy (i.e. an economy with lots of capital has a high standard of living) (Mankiw, Romer, and Weil 1992); and on the other hand, standard of living constitutes a representation which manifests itself in the human mind (Masuoka 1936:263). In this thesis I use the term standard of living to refer to a social representation, specifically a sense of well-being for people in a particular society.

Two examples of standard of living are the representations: "They are wealthier than we are" and "He is more respected than the other man is". Both are examples of representations that form in peoples' brains, and both are examples of what standard of living means to people. In the first example, the standard of living representation is related to wealth in a society in which wealth is an indication of well-being for people. In the second example, the standard of living representation is related to status in a society in which status is an indication of well-being for people. From a formalist perspective, however, both can be regarded as economic phenomena, as I argue in chapter 4.

But how can this representational form of standard of living be explained in the Bladen region? An economic explanation for the phenomenon only tells us that there will be specific or measurable levels of manos and metates at the communities, but this does not explain what people are experiencing or thinking about in the communities with respect to standard of living. Something else is needed that can extend the economic explanation to account for cognition, specifically a link from the economic states of the Bladen communities to the mental states of the inhabitants of the Bladen communities. (In other words, it must be made clear that the Bladen exchange system *constitutes* a cognitive system.)

I have discussed such a link in Section 5.9 and pages 299–302. The inhabitants of a household paid attention to (were attuned to) the frequency of manos and metates at households throughout the Bladen region. This taken together with the fact that the frequency of manos and metates fluctuated according to macroeconomic principles, specifically according to the exchange system described by Equations 6.7 – 6.9, means that the Bladen Maya would have been aware of these fluctuations.

As a result, there would have been a correspondence between the states of the Bladen exchange system and the mental states of the Bladen inhabitants throughout the economic development of the Bladen region. This information (i.e. the states of the exchange system described by the variables of the model), therefore, would have registered as a representation for the people of the Bladen. This representation is depicted in Figure 15. Two examples of interpretations of this representation which conceivably could have arisen for the Bladen Maya are: $x_3(5.0) < x_3(10.0)$ and $x_1(30.0), x_2(30.0) < x_3(30.0)$. Here, $x_1(t)$, $x_2(t)$, and $x_3(t)$ constitute the frequencies of manos and metates per average household at a given point in time, t, at Muklebal Tzul, Ek Xux, and the Lower Bladen sites, respectively.

Expressed verbally, the first relation (i.e. $x_3(5.0) < x_3(10.0)$) might be interpreted as an individual in one of the Lower Bladen communities *thinking* to himself or herself that the standard of living is considerably better at Year 10 than at Year 5 — Year 10 and Year 5 obviously have correlates in the Classic Maya calendar. Similarly, the second relation (i.e. $x_1(30.0), x_2(30.0) < x_3(30.0)$) might be interpreted as an individual in either one of the three Bladen centers *thinking* that the standard of living in Year 30 is better in the Lower Bladen sites than it is at Muklebal Tzul or at Ek Xux.

These examples illustrate two important points. The first point is that even though a Bladen individual would have had different ways of interpreting the representation, all of these interpretations are bound to the trajectories of the variables in the equations used to simulate the Bladen exchange. Thus, the possible interpretations of this representation to which the Bladen Maya would have had access can be deduced through formal modeling, analysis (i.e. assessment and testing), and simulation. What this means is that, in general, interpretability has limits and takes a form which can be reconstructed through modeling and analysis. The second point to be made is that it is possible to explain *economically* how a representation might be seen to form in the minds of Bladen Maya individuals — this representation is the standard of living with respect to manos and metates at the Bladen communities.

The implications of the first point that interpretability takes a form that can be reconstructed through modeling and analysis are described in Chapter 6. The implications of the second point warrant further discussion, since it suggests a relationship between cognitive science and economics. What is suggested from the above discussion regarding the Bladen case study is that a representational standard of living *can* be explained through economic means. This is because standard of living representation is a mental as well as an economic state. Moreover, the standard of living and the economic processes that determine it can be conceived of as being the subject matter of cognitive science, since the standard of living and the processes that determine it qualify as cognition, or supra-individual cognition. In supra-individual cognition not only is perception of the representations involved, but so is information processing. Social systems, such as the Bladen exchange system, constitute dynamical systems and hence have memory in which information can be stored and retrieved.

This *memory*, which is inherently generated in all credible dynamical systems and which takes on a social aspect in the exchange system, operates much like biological memory does in the human brain, only on a much larger scale. Instead of jointly functioning neurons there are interconnected humans and human communities. Conceived of in this way, representations — which in the case of the exchange system is information regarding the standard of living — arise within the exchange system for all of the individuals involved in the exchange system to experience. Moreover, these representations can be conceived of as remaining in people's minds by virtue of the fact that the exchange system is a dynamical system and therefore stores this information for individuals to retrieve and experience, thus explaining how it is that standard of living can constitute a persistent representation in peoples' minds, as Masuoka (1936:263) claimed. (See *Appendix F* for a mathematical explication of the information processing capability of the Bladen inter-community exchange system).

To conclude this section, I propose that understanding that people can be attuned to economic states can greatly advance the future of economic modeling by grounding models in cognition — in what is meaningful to the people whose actions the economist is modeling. An understanding of the cognitive/ economic relationship can draw the economic modeler closer to the subjects he or she is modeling by permitting the modeler a glimpse into what his or her subjects might be thinking, thereby providing the economist with a more comprehensive measurement of people's well-being.

7.6 Conclusion: The Bladen Exchange System Constitutes a Cognitive System

It was discussed in this chapter that Equations 6.7–6.9 describing exchange along the Bladen Branch can be conceived of as describing a cognitive system as well as an economic system. Thus, Figure 15 not only can be seen to represent the marginal levels of standard of living on which the exchange system in the Bladen region converged, but it can be seen as describing a supra-individual cognitive pattern or social representation which was probably perceived by the inhabitants of the Bladen region during the Classic period. In other words, the model I constructed for Bladen exchange can be seen as describing the supra-individual cognition of the Classic Maya in the Bladen region as well as the economic exchange among the Bladen communities.

Moreover, the Bladen exchange system can be seen to process information. That is, the Bladen exchange system can be conceived of as having the capability to store and retrieve representations, and as such it can be seen to process information just as neural networks do in our brain. According to the connectionists, dynamical systems with network architectures should have a certain degree of control over their own processing. This means that, in general, social dynamical systems such as the Bladen exchange system can be seen as constituting independent systems. This does not mean that the Bladen exchange system and the inter-neuronal dynamical systems of the individual inhabitants (i.e. the brains of the inhabitants) were disconnected; they were connected to each other, and it will be the objective of the next chapter to clarify how supra-individual cognitive systems can be seen to operate together with individual cognitive systems to form a more complete account of cognition.

I have described in this chapter the way in which the Bladen exchange system can be conceived of as constituting a cognitive system. I have also argued for the existence of supra-individual cognitive systems. The proposal of the existence of supra-individual cognitive systems has important implications for cognitive science because it suggests that cognition is nested. In this concept, the individual's brain comprises one cognitive "nest" which is embedded within other supra-individual *cognitive nests.* Other cognitive nests, for example, might be the dynamical systems constituting inter-personal interaction or inter-clan interaction. What follows in the next chapter is a discussion on how these cognitive nests might interact, specifically how the individual and supra-individual cognitive systems or nests might interact.

Chapter 8

Explaining Social Institutions Through a Cognitive Approach

What follows in this chapter is an extrapolation of my findings regarding the Bladen case study to social institutions in general, provided of course that the social institutions being considered can be shown to constitute cognitive systems as I have argued to be the case with the Bladen exchange system. From what was discussed in the last chapter, social institutions and, indeed, social systems that comprise society and which have been found to constitute credible dynamical systems can be conceived of as dynamical systems to which individuals are attuned. This was demonstrated with regard to Bladen exchange in Chapters 6 and 7. What this demonstration has shown is that certain social dynamical systems, such as mental or inter-neuronal dynamical systems, can be conceived of as — and therefore categorized as — cognitive systems through mathematical modeling and analysis. In this way, each social institution that is examined and which is found to be a cognitive system must be treated as if it was unique. At the same time, some generalization of the case studies examined by the analyst is required if the analyst is to work toward building a more comprehensive cognitive model.

With this basic premise in mind, my objectives in this chapter are:

- To take the first steps toward envisioning a comprehensive model of cognition which sees behavior (i.e. action) and experience as processes that allow an individual and a social dynamical system to interact. To do this I propose two integral concepts, namely *internalization* and *externalization*, which are necessary for conceptualizing how certain social institutions (i.e. credible social systems) might be engaged with the neurophysiological processes of individuals (e.g. inter-neuronal systems).

- To explore the potential explanatory power that such a model might bring to anthropology by providing examples of how such a view of cognition could be used to elucidate the anthropological and archaeological issues of:

    1. How representations can be seen to establish themselves in the minds of individuals in cultural evolutionary theory (Shennan 2002).

    2. How agency (Dobres and Robb 2000) can be understood and incorporated in formal models of social systems.

8.1 The Cognitive Approach

Individual cognition and supra-individual cognition can be conceived of as independently functioning cognitive systems operating on different levels. This is because, as I discuss in Section 7.2, the fact that cognitive systems are independent is a logical consequence of all dynamical systems. Moreover, dynamical systems that have parallel distributed architectures are noted for having distributed control throughout the dynamical system (McClelland and Rumelhart 1986; Reisberg 1997; Donald 2001).

However, neither individual nor supra-individual cognition, on its own, can provide a complete account of cognition. This is because individual cognition, generated by the human brain, and supra-individual cognition, generated by social institutions, interact. Social representations are impressed upon the individual mind through the dynamical system — manifested as a social institution — evoking the social representations. Conversely, the individual mind can be seen as changing social representations by transforming the individual's mental representations into behavior (or actions) that can change the supra-individual cognitive system generating the social representations.

In the language of information processing, being subjected to a social representation amounts to having the social representation mentally processed (i.e. simply perceiving the social representation), and affecting a social representation amounts to having one's mental representation processed socially. In other words, a representation, though it may have arisen in one cognitive "nest" (see Section 7.6), does not necessarily have to be restricted to being processed within the same cognitive nest. A representation arising in one cognitive nest can cross into other cognitive nests to be processed. This kind of processing, called *hybrid processing*, will be a major topic in this chapter and will function as the link between individual cognition and supra-individual cognition, which is critical for taking the first steps in developing a comprehensive model that can be seen as subsuming cognition and behavior.

As individuals, we have a significant degree of control over our individual cognitive capabilities. However, we do not command this degree of control over supra-individual cognition, since it involves *externalizing* one's mental representations via action and interaction in order to create or make a change in supra-individual cognition. By externalizing I mean extending one's information processing through action into the physical or social environment (refer to Section 3.4.3 regarding the notion of extended cognition). This takes an amassing of individuals to effect change at the social level, and this requires an immense amount of effort and determination from an individual as I discuss in Section 8.1.2.

Neither does supra-individual cognition determine the individual cognition, since individuals have the power to refuse or accept the social representations (i.e. social knowledge or ideology) being presented to them. Social dynamical systems, in the form of social institutions, instead can be regarded as processors *designed* by individuals for processing information for individuals, a point which was brought up in Section 7.2.1.

Supra-individual cognition is often beneficial to individual cognition and can actually decrease mental cognitive effort in the individual by shortening or cutting out the time that goes into mental processing. Not all mental representations can be processed socially, however, and I will discuss next the kinds of mental representations that can be seen as being processed by social systems.

8.1.1 Mental Representations Revisited

Clearly, not all mental representations can be processed at the social level. For example, it would probably be difficult to store the representation "*I* like that poodle" in the minds of individuals comprising one's social circle. That is, it would be unreasonable to expect more than a few people in your

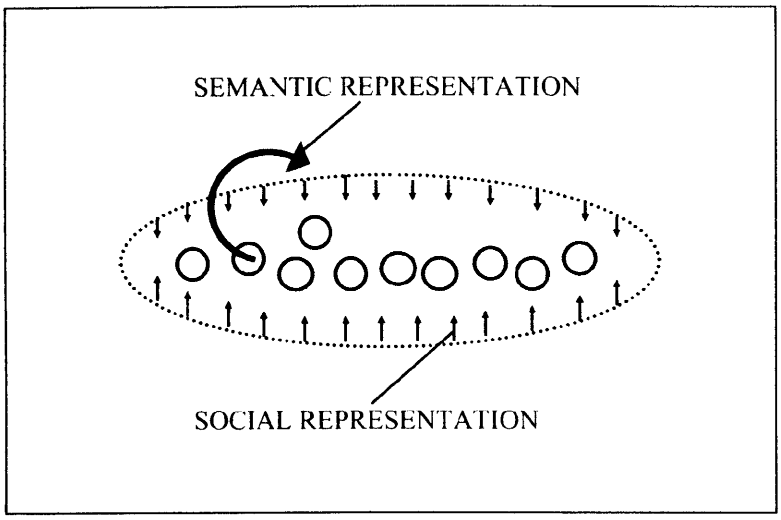

Figure 20: In this diagram mental processing (represented by the solid circles) and social processing (represented by the dotted oval) *do* affect each other. In this case individual brains can affect social systems (in the form of social institutions) via semantic representations and the actions associated with the semantic representations. Similarly, social systems can affect individual brains through generating social representations.

community to know your likes and dislikes, and as such it would be difficult to get an entire group of people constituting a society to retain this kind of information. So what kinds of mental representations can be processed at the social level? To shed light on this question I look to psychological investigations into *propositional memory* and the representations that this memory stores.

According to Tulving (1983), two kinds of propositional memory can be distinguished in the human brain: episodic and semantic. These kinds of memory can function as a framework for classifying representations based on the information that they contain (see van Dijk 1998). In this manner, I will classify those mental representations that can be stored in episodic memory as *episodic representations* and those that can be stored in semantic memory as *semantic representations*:

- Episodic representations are mental representations of events personally experienced or witnessed, or information obtained through discourse with others. Episodic representations consist of personal knowledge that is useful for oneself. Examples of episodic representations are: "Sally is my friend" or "I like burritos".

- Semantic representations are mental representations that individuals share. It is knowledge that one would expect is known by someone else who comes from the same social group. Some knowledge transcends social barriers. Examples include: "Water boils at 100 degrees Centigrade" or "The U.S.A. and U.K. are allies".

Clearly, semantic representations are the kinds of mental representations that have a greater likelihood of being processed socially and hence stored in many brains. This is because semantic representations have meaning and hence implications beyond oneself (i.e. *ego*). Semantic representations constitute the common knowledge of a social group. On the other hand, episodic representations, which refer to *ego*, are not conducive to being socially processed and, therefore, cannot be stored in many brains other than *ego* and perhaps another in one's social circle (i.e. *alter*). Therefore, I am particularly interested in semantic representations, since they are the kinds of representations that enable the individual through action and interaction to impact the social institution. I will discuss the processes by which representations and social institutions can be seen to affect each other in the next section.

8.1.2 Internalization and Externalization

The processes of retrieval and storage can be seen to be analogous to the processes of internalization and externalization. The only difference is that retrieving and storing usually refer to processes that involve a single cognitive system and which occur *within* the cognitive system, and internalizing and externalizing refer to processes that involve more than one cognitive system and which occur *across* cognitive systems. Like the processes of retrieval and storage (see Chapter 7), the processes of internalization and externalization can be seen as being complementary.

Internalization as Maintaining Social Processing

Although it has been argued that the ways we think are innate, as the evolutionary psychologists claim (e.g. Barkow, Cosmides, and Tooby 1995), our actual views on things, specifically our semantic representations, are very much the product of what we perceive in the environment after birth (D'Andrade 1995:190-193). I define **internalization** as the process whereby a pattern in the form of material or behavior in the environment invokes a *processed representation* in the mind of the individual. A processed representation is a representation that can be perceived by an individual but does not require further mental processing in order for the representation to be experienced and or comprehended. This process is not unlike *signification*, in which a signifier — which is usually taken to be material — results in a non-material signified concept in the mind of the individual.

A processed representation that already exists in the individual's mind, which comes about as the result of internalization, does not require any further mental power to enact. In other words, a processed representation does not require the utilization of one's own biological memory functions to the extent that they are utilized for conscious deliberation. Rather one is relieved of conscious deliberation by following a subconscious script (Schank and Abelson 1977). The actions involved in following a subconscious script, however, fall into the realm of externalization, specifically unintentional externalization.

Externalization as Updating Social Processing

Externalization can be seen to be the process by which a mental representation manifests itself outwardly in material or behavior and in so doing is stored in the functional organization of the material or behavioral form. Thus, externalization is the process by which mental representations are converted into actions. Changes to an existing social institution can either occur through voluntary action — what I refer to as *intentional externalization* — or it can occur through involuntary action — what I refer to as *unintentional externalization* (e.g. accidents or following the social representation being generated without questioning it).

Consciously putting a representation into action as is the case with intentional externalization uses energy, both mental and physical, whereas going on with life as it has been and simply internalizing and acting on what is being internalized, as is the case with unintentional externalization, involves less mental and usually less physical expenditure. With regard to intentional externalization, a certain degree of inertia exists that must be overcome to effect an outward change. Unintentional externalization, by remaining passive to the social representations to which one is being subjected, does not require the same degree of effort. This is similar to Lin's (2001) proposal that there are two sorts of actions: those that maintain one's resources or *expressive actions*, and those that gain more resources or *instrumental actions* (refer to Section 4.3.2). Expressive actions involve less physical effort to enact than instrumental actions and it is likely for this reason that instrumental actions are rarer, whereas expressive actions are more common. The difference between Lin's views and my views, however, rests on the fact that Lin is concerned with physical effort, whereas I am concerned with cognitive effort.

In the language of information processing, externalization constitutes storing one's representation in the functional organization of material or behavior. When the storing process is accomplished on a social level, the individual's representation is stored for the entire social group, not just for the individual or small group doing the storing. The representation being externalized can be the intention of usurping power from the ruling class by gaining control over the *functional* infrastructure, or it can be more subtle — possibly unintentional — such as an idea which leads to an innovation that changes the existing technology and, hence, the socio-economic relations which were formed as the result of the earlier technology. Whatever the case may be, externalization is a way in which a representation can effect a functional change, and externalization can be actuated by any individual in the society.

Externalization can be seen to be a process which results in the establishment of social institutions, such as inter-community exchange or political alliances and allegiances that can outlive any single individual or individuals. In this manner, externalization can be regarded as an *investment* for individuals and groups who are part of society for as long as the society is maintained.

Summary of Internalization and Externalization and Their Complementary Nature

Cognition involves both externalization and internalization. Externalization is the process by which an individual effects behavioral changes on a supra-individual level through action and interaction and, in so doing, causes the individual's representations to be stored externally in social institutions. Internalization is the process by which representations that have been stored externally in social institutions are accessed and become part of an individual's cognitive repertoire. As such, internalization and externalization can be conceived of as complementary processes, often operating in concert, each reinforcing the other. In order for human beings to have internalized a representation, there had to have been a time in which a representation was externalized. Conversely, human beings can often be seen to be responding to the internalization of social representations through externalizing the same representations being internalized or externalizing different individual representations through unintentional or intentional means, respectively.

8.2 Conceptualizing Internalization and Externalization: Filling in the Gap Between Individual Cognition and Supra-Individual Cognition

Is supra-individual cognition really transpiring outside of the individual's brain? In this thesis, I have proposed that supra-individual cognition occurs at a level or scale larger than the individual's brain, but if this is the case, then how are the social representations, which are stored in the supra-individual cognitive system, retrieved by the individual's nervous system during internalization? Conversely, it is easy to see how individual cognition updates supra-individual cognition in the process that I have termed externalization — it does so via action — but how does action allow the brain to store representations in supra-individual cognitive systems?

My proposed explanation of individual cognition and supra-individual cognition up to this point has been abstract. I have proposed that there is an individual cognitive system and that there are supra-individual cognitive systems, each of which is self-organizing and self-controlling and therefore independent to a certain degree. As such, mental and social processing systems, upon first impression, seem divided and unable to be conceptualized together even when it is accepted that they interact with each other through internalization and externalization.

Implicit in the discussion on internalization and externalization was the fact that individual cognition affects supra-individual cognition *intermittently* via action whereas supra-individual cognition subjects the individual's brain to representations on a relatively *continuous* basis. This concept parallels a cognitive evolutionary view of the interactive bridge between mental processing and social processing. That is, it would be adaptive for brains to acquire the capability of utilizing the social environment (i.e. institutions) to "relieve" mental processing to some degree.

Whereas the self-organizing, self-controlling view of cognitive systems is helpful for understanding the benefits of interaction among cognitive systems — individual cognitive systems use supra-individual cognitive systems in facilitating mental processing and, in a manner of speaking, supra-individual cognitive systems use the individual's brain as a place to manifest representations — it does not fully explain cognition. The reason that the self-controlling view does not fully explain cognition is that individual cognition and supra-individual cognition, while being independent, *are not isolated from each other.* They constitute one whole cognitive system in which individual and supra-individual cognitive systems can be viewed as subsystems, and it is this that allows us to conceptualize the interactive dynamics between individual cognition and supra-individual cognition.

To suggest otherwise — that there is a gap between the individual cognitive system and the supra-individual cognitive system — would imply that the nature of representations are such that they are *transmitted* from the supra-individual cognitive system to the individual cognitive system during the process of internalization. This implies that representations are entities of a sort that can cross the gap between social institutions and brains, something like *memes* (Dawkins 1976), but different from memes in that they would not be transmittable between individuals, but between an individual and a social institution.

This concept, however, involves a level of abstraction that is not necessary to or consonant with cognitive systems as I have described them. Representations do not need to be transmitted across hypothetical gaps when they can be conceived of as being part of dynamical systems that generate representations, and when individuals are subjected to representations through their attunement to the dynamical systems.

8.2.1 Conceptualizing Externalization

In the beginning of this section I asked how an action can result in storing mental representations in supra-individual cognitive systems. An individual's actions can be conceived of as affecting the supra-individual cognitive system because the individual *is part of* the social system constituting the supra-individual cognitive system. In this way, an action on the part of the individual will have a corresponding effect on the supra-individual cognitive system.

For example, if an individual is prompted by a representation to interact with another individual in a certain way based on this representation, then (see Section 7.1.2) the first individual is essentially *fixing* the constraints of the interactive system subsuming both individuals. In doing this, the first individual can be seen to set up the interactive system to store a representation. (In this example, the representation that prompts the action is a mental representation and it is stored in the interactive system as a social representation.) Thus, representations can be conceived of as being stored by an individual by *acting in* dynamical systems that subsume that individual and the social environment of which the individual is a part. This conceptualization merges the two abstract notions of mental processing and social processing into a more complete account of cognition. Figure 21 should help clarify this conceptualization of externalization.

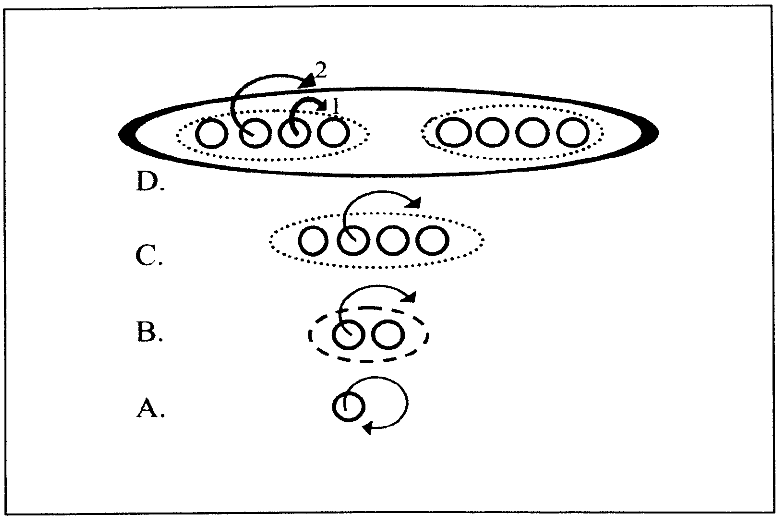

Figure 21: In this diagram portraying externalization, an individual's action resulting from conscious decision-making is invoking changes to various different social systems or social institutions. *A.* simply shows how cognition arising from an individual's neural substrate is controlling the individual's motor functions (e.g. lifting an arm). *B.* shows how cognition arising from an individual's neural substrate (i.e. a *mental processing system*) is making changes to the cognitive system (or *social processing system*) formed between two friends, hence, changing the cognition that arises from this inter-personal cognitive system. *C.* shows how cognition arising from an individual's neural substrate (i.e. mental processing) is making changes to the cognitive system formed among several individuals (i.e. a community of individuals), hence, changing the cognition that arises from this inter-personal cognitive system. *D.* shows how cognition arising from an individual's neural substrate (i.e. mental processing) is making changes to the cognitive system formed between members of one's community (1), which in turn affects inter-community interaction, resulting in changes to the cognition that arises from this inter-community cognitive system (2). Note how in *D* changes are effected through the associated cognitive system in a cascade fashion rather than through transmission.

8.2.2 Conceptualizing Internalization

With this merging of individual and supra-individual cognitive systems, a representation generated by a social institution should automatically generate an associated representation in the brain of the individual. To clarify this process by which a social representation becomes a mental representation for the individual it is key to realize that as long as the human brain is attuned to the features of a dynamical system — most important being the states of the system — then this means that there are neurons or groups of neurons in the brain that correspond to the states of the dynamical system in the environment (recall Section 7.3.1). As such, a change in the states of the social processing system can be seen to effect a corresponding change from the neurons designating the states of the social processing system within the brain.

Neural networks of the brain have the ability to mimic any dynamical system in the environment. Perhaps not surprisingly, this is precisely the reason why neural networks are so extensively used by engineers. Engineers use artificial neural networks to approximate all sorts of dynamical systems, whether they are mechanical or electrical, and for this reason neural networks have been characterized as "universal approximators".

Whereas the actual information processing of social representations can be seen to occur on a social scale subsuming the individual's brain, it is conceivable that the effects of a social system or institution would have ramifications within the brain. In this way, representations can be seen to arise *in situ* within the brain and never actually *need* to cross the hypothetical gap between the supra-individual cognitive system (e.g. an inter-community exchange system) and the individual cognitive system (i.e. the inter-neuronal dynamical system). Figure 22 should help clarify this conceptualization of internalization.

8.2.3 Summarizing the Conceptualization of Externalization and Internalization and Their Implications

To summarize, the process of externalization can be seen to involve an individual's actions in storing mental representations in a supra-individual cognitive system by fixing the constraints of the supra-individual cognitive system. Thus, the information processing involved in externalization (i.e. storing representations) can be seen as a dynamical system which subsumes both the individual and the social environment and which functions at a scale larger than the brain. On the other hand, internalization (i.e. retrieving representations) can be conceived of as occurring simultaneously at the social scale as well as within the brain, since a social system's states can be seen as having corresponding effects on neural states (assuming that the social system is also a cognitive system [i.e. a system to which individuals are attuned]).

8.3 The Cognitive Approach: Explaining Representation

One key issue that a cognitive approach to society can help to clarify has to do with the nature of a *representation.*

In recent years, new approaches to cultural evolution have increasingly attracted a following in archaeology. Cultural evolution (as defined by Boyd and Richerson [1985] and Shennan [2002]) relies heavily on the notion that persistent cultural traits or representations are the result of traits or repre-

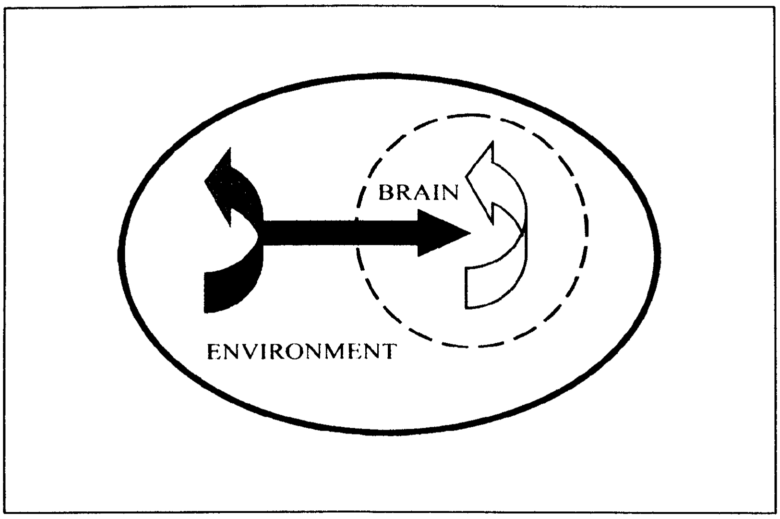

Figure 22: In this diagram portraying internalization, a dynamical system in the social or physical environment is being perceived by an individual's brain. In other words, because the individual is locked onto some feature of a dynamical system, the individual follows its changes through time. Whatever occurs to this feature that is attached to the dynamical system within the social or physical environment will also happen within the individual's brain as long as the individual remains attuned to the dynamical system. Provided that there is attunement, this means that for every dynamical systemic state there will be a corresponding mental state. Because of the nature of internalization, the analyst needs only to explain what is happening to the dynamical system in the environment in order to understand what is occurring within the individual's brain.

sentations being successfully selected for over time. Some of these cultural informational units, called *memes*, are perpetuated through discourse and eventually become shared by members of a society (Dawkins 1976). Though the notion of the meme is not necessary for an evolutionary framework, the notion that culture is information which is transmitted and then "inherited" through *social learning* is important for cultural evolutionists in conceiving of culture as an inheritance system (Shennan 2002:35-36).

There are difficulties, however, with conceiving of culture as an inheritance system. This is because the representation or meme does not function in the way that would be expected of it if it was the analog to the *gene* in biological evolution (Hull 1988:37; Lake 1998:86). However, a more pressing problem for cultural evolution from a cognitive standpoint is how the cultural evolutionary paradigm conceives of social learning. Cultural evolutionists envision learning as transmission, and this, in turn, affects the way that cultural evolutionists conceive of representations. In other words, the cultural evolution school sees representations as being transmittable.

8.3.1 Transmittable Representations

Two kinds of representations fall under what I refer to as the transmittable paradigm of representations: personal representations and social representations. *Personal representations* are representations that are formed and are particular to the individual (van Dijk 1998:28). *Social representations* are personal representations that are shared amongst two or more individuals (van Dijk 1998:28-31). Personal representations can be said to become shared through transmission, much as diseases are spread, and it is for this reason that the transmittable approach is referred to as epidemiological (Sperber 1996).

In the transmittable view of representations, personal representations have the potential of becoming social representations; that is, all social representations were personal representations at one time. Some schools of thought, however, use a different terminology. For example, according to the cultural epidemiological school of thought (Sperber 1996), there exist representations and *memes*. A representation is an idea that an individual comes up with, and a meme is a representation that can be successfully replicated and shared by several individuals (Sperber 1996:100-101). This provides a model that makes it relatively easy to envision how representations are absorbed, altered, shared, or rejected by individuals because representations are seen as particles or units that can be altered or passed on to someone else, mainly through discourse. The transmittable view of representations is certainly the most popular amongst archaeologists and anthropologists today, especially amongst those who are closely allied with the cultural evolutionists and epidemiologists (e.g. Sperber 1996; Shennan 2002).

8.3.2 The Problem with Social Learning

According to cognitive scientists, learning — or the process by which representations are stored or retained — is a functional phenomenon, called information processing, in which a dynamical system or network stores patterns through fixing the constraints of the system. This is the way that learning has been treated for the past forty years in the work of Grossberg (1967, 1970a, 1970b) and others (recall Chapters 2 and 3). However this is not how learning is depicted in cultural evolution. In cultural evolution, learning is regarded as the transmission of ideas, not as a capability of a system. The term "social learning," which is an important concept in cultural evolution, is a case in point.

The difficulty with conceiving of learning as transmission is that the process by which representations are transmitted does not constitute learning. Learning in the transmission model needs to involve mechanisms that allow some representations the ability *to be retained* by the recipients once the representations have been transmitted. As it stands, the transmission model lacks a feasible concept of how representations are stored, which is essential in any model of learning. Cultural evolutionists assert that the mechanisms that allow representations to be retained after they have been transmitted is either selection or copying. Through a series of mechanisms (Boyd and Richerson 1985), representations either battle it out until some finite number of the representations succeed in being "inherited" for some period of time (e.g. direct and indirect transmission) or else they are passively adopted (e.g. conformist transmission).

However, the mechanisms responsible for how social representations are selected in cultural evolution — direct transmission and indirect transmission — are not explanations for how social representations succeed in being formed and retained; they are merely descriptions of the different ways that social representations can be "inherited". Game theory and decision theory facilitate the explanation of how different social representations may compete against each other after the representations have already manifested themselves in individuals — *after* they have been learned or retained to some degree. However, cultural evolutionary theory does not account for how a social representation is generated in the first place such that the representation is retained in multiple minds.

With regard to conformist transmission, the idea is that representations are selected before they are retained, so all one needs to do is copy them. Still, even in conformist transmission, in which there appears to be no learning going on at the time the representation is copied, the representation had to arise from some place and in some manner. The process in which representations arise, however, is not adequately explained and the cultural evolutionist is forced to assume the representation's existence *a priori*.

In light of the conceptual difficulties which cultural evolutionists face, I have proposed another way of looking at social learning in this thesis. I have looked at learning from an information processing perspective and built a notion of what a representation is from a functional basis rather than an epidemiological one.

8.3.3 Non-Transmittable Representations

Non-transmittable representations are the kinds of representations I have been discussing throughout this thesis. Non-transmittable representations are formed as the result of certain kinds of functional organizations. The most obvious functional organizations capable of processing information are dynamical systems.

The cognitive approach can provide a parsimonious explanation for how representations are retained by grounding the notion of representation in *functionalism*.[1] In the cognitive approach, representations must have a functional basis in order to be generated. These functional bases exist on many different levels or scales from the inter-neuronal scale to the inter-societal scale. As such, an idea that manifests itself on an inter-neuronal level can only be *built into* a high-order level (e.g. inter-community scale) through some physical change to the high-order cognitive system. For example, by changing inter-community relations, a ruler in one community can affect what kinds of representations the inhabitants of all of the communities are being

[1] I take functionalism to mean *strong functionalism* as I described in Section 3.2.3.

presented with. This shows that a representation formed in an inter-neuronal dynamical system can effect a change in social representations only through physically changing the functional organization of the cognitive system responsible for generating the social representations. This appears superficially similar to the idea or metaphor of a particle of information being transmitted from one individual to another. In actuality the process in which social representations arise (i.e. retained) is training higher-ordered cognitive systems to generate representations.

Although non-transmittable representations emerge from dynamical systems to which individuals are attuned, these representations still require a material basis in order to be generated. That is to say that the functional organization of the material basis must be arranged in such a way that it constitutes a dynamical system. Thus, even though information processing capability is not a material phenomenon but rather a functional phenomenon (since information processing is substrate independent), it does require *some* material substrate in order to generate information processing capability.

As such, non-transmittable representations are linked to a material substrate. They are not transmittable because they do not need to be transmitted. Whereas transmittable representations replace other representations by infiltrating the minds of people and battling it out for superiority within the minds of individuals, non-transmittable representations replace other representations by effecting a change in the organization of a material basis generating the other representations. By changing the functional organization of the material basis that is generating an old representation, a new representation is produced to replace the old representation. In this way, a non-transmittable representation usually has an observable concomitant (i.e. *action*).

Discourse is a perfect example illustrating the material and representational dynamic. For those who assert that representations are transmittable, discourse is seen as a vehicle for infiltrating the brains of individuals with representations. In contrast to this, the non-transmittable paradigm asserts that discourse is a means for establishing social institutions (with the proper functional organizations) that can, in turn, generate representations at a scale larger than the inter-neuronal level. In the non-transmittable view, information is relayed between people in order to establish the social institutions, but it is the social institutions that are responsible for evoking long-standing representations that have an impact on more than one individual. The information that is relayed between people functions so as to enable people to work together to form social unions and institutions which have a dynamic of their own for generating representations.

Conventional cultural evolutionary thought proposes that representations are transmittable particulate entities that become shared among individuals. In this way, representations are spread in a process called cultural transmission (e.g. through discourse). In other words, representations are particulate entities that are distributed in *series*. One individual comes up with an idea and that idea is spread to other individuals and eventually the idea becomes a social representation.

However, from what we know of how representations are stored in memory, this is not a viable model for how representations are formed. Based on what we know about information processing, a viable model to explain how representations are formed has representations constitute *layers* emerging from dynamical systems to which individuals are attuned. This means that ideas can manifest themselves structurally, socially, and/or simultaneously in many individuals, and therefore in *parallel*. In short, the cognitive approach, which is based on how information is processed, can propose an explanation for the processes that lead to the formation of a representation.

8.4 The Cognitive Approach: Explaining Agency

The study of agency involves the study of actors and their social relevancy — that is, how individuals and small social groups within society can affect the social systems or institutions that hold sway over the individuals and small social groups (Dobres and Robb 2000:8). Agency is typically studied through action (e.g. Joyce 2000:71). However, agency can also be studied using the cognitive approach. The cognitive approach is a comprehensive means of approaching agency, since it considers the mental processes that initiate physical actions as well as the physical actions that result in the changes to the social institution. The cognitive approach incorporates representations in the social life of the individuals being studied and this is important since representations affect and are affected by action.

8.4.1 The Cognitive Approach as an Alternative to the Action Approach

For many agency theorists, agency constitutes the individual's or small social group's ability to act voluntarily in such a way as to effect changes in society (e.g. Hodder 1987:6). What is explicit is the fact that the individual must act, and I refer to this emphasis on studying agency through action the *action approach.* However, what is implicit is that agency begins with an intention or representation and follows through with this representation via an associated action. In the action approach, the representations that sparked the actions are not commonly considered, or if they are considered, the representations are left implicit. This has a detrimental effect on any attempt to explain behavior in society since representations — mental and social — are integral in shaping ways in which individuals and small social groups act or behave. Unlike the action approach, the cognitive approach sees actions as not only being initiated by representations but actually being material or behavioral manifestations of representations which elicited the actions. As such, representations and cognition would be featured explicitly in agency studies that utilize the cognitive approach, since action is seen as being synonymous with cognition.

The fact that action can be regarded as synonymous with cognition has been implied throughout the last two chapters. Actions in the social environment can be conceived of as dynamical systems if assessed as such, and this means that they can be seen to have information processing capability. If these systems are perceived, the dynamical systems constitute cognitive systems. In this way, actions in the social environment can be seen to be cognitive systems. The implication is that a common currency pervades both action and cognition, and this common currency is information in the form of representations.

Points at Which the Cognitive Approach and the Action Approach Intersect and Do Not Intersect

The cognitive approach and action approach intersect on the point of voluntary action and do not intersect on the point of involuntary action. I discuss these points below.

In the action approach, action is regarded as a physical phenomenon with the intent of making changes to the social system subsuming the agent, the assumption being that action is voluntary. As such, action as it is portrayed by the action approach can be seen to intersect with the cognitive process, which I refer to as *intentional externalization.* In this case, a representation affects the functional organization of the society in such a way as to influence it to generate the desired representation.

However, the cognitive approach also includes involuntary actions which are significant enough to change the functional organization of the social institution, often causing it to generate unintended representations. These actions can be referred to as *unintentional externalizations* (see Section 8.1.2), which up to this point have been little discussed, but are still capable of being handled by a cognitive approach. The action approach to agency, on the other hand, has difficulty reconciling the effects of unintentional actions (Dobres and Robb 2000:10) since it is traditionally associated with voluntary behavior (Dobres and Robb 2000:4) and the effects thereof on the rest of society. Involuntary actions, however, are important since they change the functional organization of social institutions in society; and this changes the representations being generated, which in turn affects the way in which individuals and small social groups voluntarily behave.

In a sense, the cognitive approach is more comprehensive than the action approach not only because it can account for agency from the moment it emerges in cognition to the moment it finishes its action, but because it can include involuntary actions and explain how they can effect changes in social institutions and the representations they generate. This is all possible since voluntary actions and involuntary actions, whether they stem from the individual, a small social group, or social institution, can be conceived of as sharing the currency of information in the form of representations. In other words, the cognitive approach can account for actions since actions can be conceived of as cognitive systems.

8.4.2 Agency and Systems

To use the cognitive approach requires the utilization of the notion of a "system" since the cognitive approach relies on the fact that cognition arises from dynamical systems to which other information processors, particularly humans, are attuned. Therefore to utilize the cognitive approach to explain agency entails a defense of the concept of the system in archaeology, which until the 1990s was considered to be an inadequate means for expressing the effects of agency (Lake 2003:2).

Agency in archaeology came about to some degree as a response to systems theory in archaeology (Dobres and Robb 2000:6; Lake 2003:2). Agency advocates asserted that modeling a social phenomenon as a social system neglected to incorporate the individual or small groups that would have been integral in forming the social system's dynamics (Graham 1991). Their criticism was merited; however, their rejection of the concept of a system as a means of conceiving of society and its social institutions was premature. The social system as it came to be regarded was commonly conceived by archaeologists as being a *linear system.*[2] As a result, the notion of a social system as a linear system was seen to be too mechanistic for the purposes of modeling society and all of its intricacies. The main complaint against the concept of the system was that it could not incorporate the effects individuals or small social groups and therefore was unable to depict social complexity. As a result, systems and the models that describe them entered a hiatus (Lake 2003:2).

When the notion of agency emerged it was predominantly post-processual (e.g. Hodder 1987, Shanks and Tilley 1987). However as more processual-

[2]There are exceptions, however. See Renfrew and Cooke (1979) and Renfrew, Rowlands, and Segraves (1982).

driven archaeologists began exploring the concept of *nonlinear systems*, it became clear that agency might be incorporated into a system after all (e.g. McGlade 1997, van der Leeuw and McGlade 1997). Nonlinear systems are dynamical systems that have have several distinctive characteristics of which the most important in our discussion is sensitivity to initial conditions and the ability to have more than one equilibrium. Sensitivity to initial conditions means that different starting points for the system can yield drastically different outputs and have different end points (i.e equilibria). For processual archaeologists, the notion that social systems could be conceived of as nonlinear systems held out hope that nonlinear systems and the models that describe them would provide the modeler with a clearer sense of social reality. This is because the notion of small scale perturbations to the initial conditions of the nonlinear social system could be considered akin to individuals and small social groups effecting change in the social system that subsumes the individuals and small social groups (Spencer-Wood 2000:116,121).

Though it seems like a promising idea, I argue that associating agency with initial conditions is an impractical way of conceiving of agency. Agency acts on the social system continuously throughout its history or evolution, not just on the initial states of the system's development. Moreover, agency is built into the system and becomes part of the social system, and is not just superimposed on the social system. Therefore, agency is actually important in contributing to the trajectory the social system takes. The notion that agency is a sustained phenomenon, and not simply a one-time event, mirrors what can best be described as "noise" rather than sensitivity to initial conditions. I propose, therefore, that utilizing the notion of noise makes it possible to introduce agency into social systems while maintaining the validity of conceiving of society and its institutions as systems.

It should be pointed out that the concept of noise is a relative one and depends on the subject. In this way, if the social system is the subject, then agency is the noise, and if the individual is the subject then the social system constitutes the noise. In this thesis the focus has been on the social system as subject.

Agency as Noise

What has been argued in the last section is that the notion of a system is a concept which can adequately cope with agency. In circumstances that permit it (e.g. where historical information is available), agency can be introduced into the social system discriminately. In cases where we do not exactly know what agents were doing, but we still want to introduce the effects of agency into the system, we can introduce agency into the system as noise.

Unlike conceiving of agency as perturbations to the initial conditions of the social dynamical system, agency can be conceived of as random fluctuations to the constraints of the social dynamical system. This noise to the constraints is called *multiplicative noise* and is different from *additive noise*, which is often used in engineering models (Milton 1996). Agency, as multiplicative noise, affects the development of the social system continuously throughout the evolution of the system. As a result, the agent is never excluded at any time from having an effect on the social system. In addition to this, since the noise is affecting the constraints of the system, it is effectively operating on the system endogenously instead of exogenously. As a result, agency is *built into* the system and therefore plays an important role in shaping the course that the system takes. Whatever approach is taken to conceive of agency — whether it is the cognitive approach or the action approach — noise is an adequate means of representing agency.

Next, I illustrate the effects of agency using the cognitive approach on the Bladen communities. The reason for using the cognitive approach rather than the action approach, as I discuss above in Section 8.4.1, is that it is more comprehensive since it includes the representations that initiated the actions as well as the actions themselves. Because both representations and actions affect each other it is difficult to see how they can be separated, as is commonly done using an action approach.

8.4.3 Revisiting the Bladen: A Formal Cognitive Explanation for Agency

As I have already argued above, agency can be explained with a cognitive approach, specifically with the concept of externalization. I will demonstrate how intentional externalization or agency can be realized in a hypothetical scenario among the Bladen communities in which the elite — the agents in this case — are working at odds with the commoners.

In the cognitive approach, supra-individual cognition functions in facilitating the information processing of individual minds, but often changes are made to the way that the exchange system socially processes the marginal standard of living representation. For example, the elites of the Bladen communities may be envious of the high standard of living representations their communities' populations have been receiving. Therefore, the elites of the communities try to change the functional organization of the exchange system so as to lower the marginal standard of living for their subjects. In doing this, the elites hope that their subjects will not acquire high status.

To change the standard of living representation, the elites must change the functional infrastructure, perhaps by advocating policies that increase population growth at the communities (n) or increase the number of rituals involving manos and metates (δ) (recall that in Equations 6.7-6.9, $A = n+\delta$); in this way, there will be fewer manos and metates in circulation. This will, in turn, lower the representational community rankings. The crucial step, then, for the elites is to externalize the small group representation of "lowering the standard of living of our subjects". Only then can the supra-individual cognition generated by the Bladen exchange system be changed. Countering this will be the commoners who are trying to increase their standard of living representations by refusing to partake in rituals (δ) involving the usage of manos and metates. These changes to n and δ will cause A to modulate and in this way small social group cognition can be seen as affecting Bladen supra-individual cognition via externalization. In so doing, the small social groups make changes to the social representation that is being internalized by all of the people of the Bladen.

The effect of the conflict of interests between the commoners and the elites (i.e. the agents) can best be modeled by updating one of the constraints, namely A. The updating of A can be approximated with normally distributed random fluctuations, where A denotes the mean of these random fluctuations (Figure 23). The premise behind this is that interested parties or individuals are externalizing and in so doing incurring changes to the exchange system that subsumes them. By externalizing their representations, individuals and interested parties change the representations they have been internalizing.

To recapitulate how the Bladen case study illustrates earlier points about agency, we can conceive of the agents as constituting a small group of elites who are trying to lower the average standard of living representation through externalization. In doing this, the elites change the functional organization of the exchange system, such that a newer, lower standard of living representation is generated from the functional organization of Bladen exchange. This change occurs throughout the exchange system's development by one elite person or another and produces the effect of noise built into the exchange system. This "small-scale" noise from the elites shapes the exchange system and affects the trajectory that the exchange system takes.

The most important point is that there is *continuous* feedback occurring between the individual or small groups of individuals and the subsuming social system, in our case Bladen exchange. This continuous feedback is integral for permitting the individuals to make changes and for shaping the encompassing social system's development. This feedback is not rooted in action without cognition, but rather rooted in cognition and the continuous interplay between externalization and internalization.

8.5 Conclusion: A Comprehensive Model of Cognition Resides on a Bridge

In this chapter, I use the term externalization to refer to the process or action initiated by individual cognition by which representations are stored in supra-individual cognitive systems. Similarly, I utilize the term internalization to refer to the process by which representations are retrieved from supra-individual cognitive systems and by which they are manifested in the brain of the individual. Externalization and internalization are processes that bridge the gap between the individual and his or her individual cognition, and the social institution and its associated supra-individual cognition. Understanding how the processes bridge individual cognitive systems and supra-individual cognitive systems is integral to understanding how the study of social institutions can be seen as a part of cognitive science.

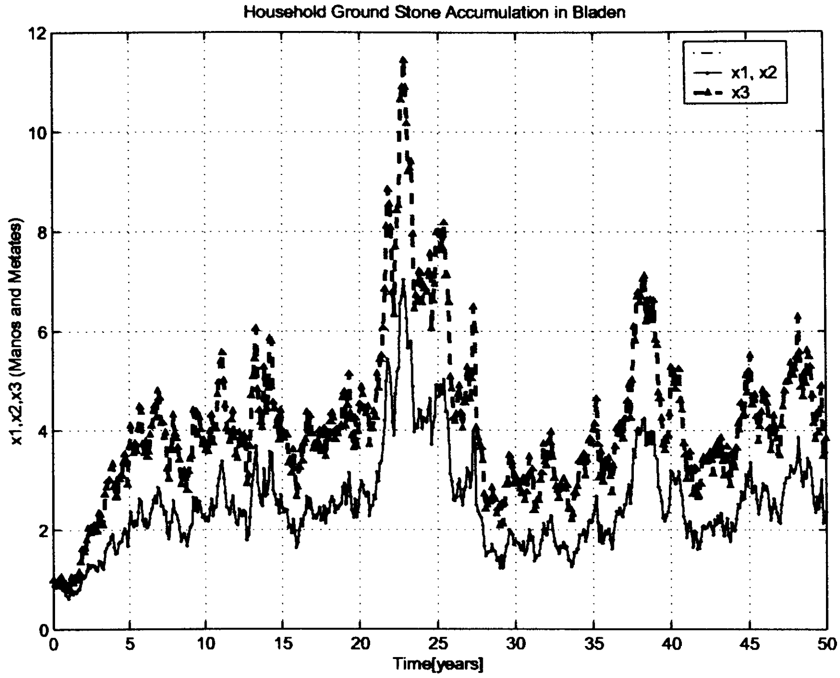

Figure 23: This plot depicts the results of the dynamical system described by Equations 6.7–6.9, where r is a uniformly random fluctuating parameter in the range $[1.0, 2.0]$ and A is a normal distribution with mean 0.23 and variance 1.00. The diagram of this stochastic response shows how the household level of manos and metates at Muklebal Tzul (x1), Ek Xux (x2), and the Lower Bladen (x3) sites grew through time. Mano and metate frequencies at households in Ek Xux and Muklebal Tzul are the same, whereas the frequency of manos and metates at households in the Lower Bladen sites rises clearly above this level. The difference between Figure 15 and this figure is that this figure incorporates individual cognition and associated action. These actions, which come from both the elite and the commoners of the Bladen communities, affect the constraints of the exchange system that is producing a standard of living representation that all the individuals in the system experience. Here, the rulers can be seen as trying to decrease the mano and metate frequency and associated standard of living by encouraging population growth or ritual usage of manos and metates (i.e. increasing n and δ, respectively) and the commoners can be seen as trying to increase their standard of living by not participating in rituals involving manos and metates (i.e. decreasing δ).

The main purpose of this chapter is to take the first steps toward realizing a model of cognition — based on how mental representations arise within nervous systems — which sees social institutions as supra-individual sources of cognition. The general idea is that the social institution can be conceived of as a supra-individual cognitive system to which individuals are attuned. A social institution, therefore, functions as an extended information processor to the individual's brain and therefore facilitates processing in much the same way that a computer or calculator facilitates the individual's cognitive capabilities. In this way, the supra-individual cognitive system extends cognition in a manner similar to how external memory devices proposed by Donald (1991) and Clark and Chalmers (1998) extend information processing capacity. The only difference is that social institutions can be seen as having a much longer development than most of the other external cognitive devices which are responsible for the last stage in Donald's (1991) cognitive evolutionary scheme.

I explored two theoretical paradigms which are commonly used among anthropologists and archaeologists and I showed that a cognitive approach can be used as an alternative to these paradigms. I also showed that the cognitive approach has advantages over these other paradigms. The cultural evolutionary paradigm neglects to account for how social representations arise and how they are retained in the minds of individuals. The response from the cognitive approach is to regard social representations just as we would mental representations and in this way explain how social representations are formed and retained. The emphasis on agency arose in response to systems theorists' lack of attention to the actions of individuals or small social groups. I showed in this chapter that the cognitive approach can account for the agency of individuals and small interest groups as "noise" built *into* the social system. The fact that the noise is part of the system has the effect of giving the social system a unique character which it would not have had without the incorporation of agency.

Conclusion

Classic Maya ground stone exchange in the Bladen region of the Maya Mountains was not solely a means by which people obtained goods that they required or desired, nor was it solely a means through which individuals could gain prestige or socialize. As much as these socioeconomic reasons are important for shedding light on why Classic Maya exchanged ground stone, and for gaining insight into the past human lifeways of the Classic Maya, the purpose of this thesis was to go beyond what my case study tells archaeologists about how the Classic Maya exchanged goods. Although exchange is a social institution that has very pragmatic reasons for existing (i.e. I want it so I seek to obtain it), exchange can be assessed and can therefore be conceived of as a dynamical system capable of generating supra-individual cognition. In this way, the exchange of ground stone in the Bladen region was seen as a process in which the relationship between social institutions and cognition could be illuminated. This entailed demonstrating that ground stone exchange within the Bladen region could be seen to form a *dynamical system* to which the Bladen inhabitants were attuned (recall chapter 7).[3]

In this thesis, I began with the premise that aspects of human behavior can be represented as fundamentally economic. I used this characteristic to

[3]Recall that cognition refers to information processing capability as well as the capability of being perceived by individuals.

show that "thinking" individuals are aware of the economic patterns surrounding them. This may at first glance sound deterministic — that we are trapped into thinking in a manner that is determined by economic systems that we have constructed — but it is not deterministic. We are aware of the patterns that emerge from economic systems and in most cases we continue to follow these patterns, but this does not mean that we all respond in the same way to the patterns we perceive.

As I have discussed in Chapter 8, mental processing (or individual cognition) and social processing (or supra-individual cognition) can be conceived of as being independent of each other in that they can be seen to operate at different scales, hence forming separate dynamical/cognitive systems. Because dynamical systems can be seen to be independent systems, these dynamical systems exert a certain amount of *control* over their own functioning. In addition to the autonomous nature of cognitive systems, cognitive systems can also form networks, and this tends to distribute control among the functioning constituents of the networks (Reisberg 1997).

Even though cognitive systems such as a brain and an exchange system can be seen to be independent, they can interact and indeed have impact on each other as I discussed in the last chapter. For example, variations in behavioral responses to a general social trend can be introduced by individual conscious minds, resulting in changes which influence the supra-individual cognitive system and the social representations it produces. So it should not seem as if the individual plays no role in affecting and in some cases changing the social representations to which the individual is subject (see Section 8.4).

To what extent supra-individual cognition has control over its processing is debatable. However, if the number of nodes and inter-connections determines how much control cognitive systems exert over functioning and organization (Wu 2001:7), then it would seem logical to expect that the human brain would have far greater control over its processing than a social institution, such as an exchange system, would have over its processing.[4]

Toward a Fundamental Theory of Cognition

The assumption that the human brain has far more control over its own faculties than a social institution has over its processing leads me to propose that individuals can manipulate social processing. This manipulation can be seen in two ways:

1. The first way is to envision manipulation as *unintentional* — as an adaptation to ease cognitive expenditure that is biologically driven. In this view, an individual's brain manipulates social processing through action in order to alleviate the brain from having to process information on its own.

2. The second way is to envision manipulation as *intentional* or calculated. In this view, an individual's brain manipulates social processing through action in order to gain control over the individual's life.

These views are related since they can both be conceived of as modes of externalization, and thus can be seen as links between the cognition manifested in the individual's brain and the cognition formed by society's institutions. The result of these explorations suggests that because cognition can be seen to extend to social behavior, cognition not only encompasses biological

[4]There are in the human cortex about 10^{11} neurons with 10^{15} synapses (Wu 2001:7), which is far greater than the number of interacting communities on this earth, let alone the number of interacting individuals on this earth.

brain functioning, but it can also be seen to encompass social institutional functioning. In other words, it should be possible to conceive of the processes behind brain and certain social institutional functioning as not only being connected, but also as being based on the same fundamental mechanics, and therefore subsumed by a common model.

The idea that cognition is substrate independent has important implications for cognition because it suggests that cognition is not necessarily the subject matter for psychology. Since cognition manifests itself within the individual, and can be seen to manifest itself within social groups, and between the individual and social groups, cognition has to be studied in social as well as individual contexts. Moreover, not only can the brain and its functioning be conceived of as part of cognitive science, but so can the study of social institutions. This means that aspects of economics and sociology might some day be studied as cognitive science. Such a cognitive science, as I envision it, would not only study cognition in the individual but it would study cognition in the individual and in society. The proposal that many aspects of social life can be seen as being analyzed as cognitive science has important implications for archaeology and anthropology. I discuss these implications in the next sections.

Cognitive Modeling Procedures and Their Implications for Archaeology and Anthropology: A Cognitive Approach to Society

The main way to construct a cognitive model of a social or economic phenomenon is to construct a model of a phenomenon that can be tested against empirical data to ascertain if the model represents a cognitive system. Models of contemporary social and economic phenomena can be tested for cognitive attunement in the way that Turvey and Carello (1995) test for attunement — the analyst's model can be tested to see if the subjects being analyzed are attuned to the constraints or the states of the dynamical system that the model describes. And models of ancient social or economic phenomena can be tested not through interviewing one's subjects, obviously, but by modeling case studies that have enough historical or archaeological information to infer (propose) what people were thinking, as my case study of the Bladen has shown.

One issue that a modern economist does not face as often as an archaeologist faces is *complete* detachment from his or her subjects. The modern economist is commonly a member of the the society he or she models and therefore being etic amounts to being emic to some degree as well since the economist is modeling the economy based on his or her own experiences, which are of course a part of the supra-individual cognition which subsumes the economist. The archaeologist, on the other hand, does not have the good fortune of being in the economist's position. This is because the archaeologist often is not subsumed by the supra-individual cognition of the people he or she is studying. The archaeologist is detached from his or her subjects by time and often space.

On the other hand, the archaeologist or anthropologist is frequently closer to his or her subjects than the modern economist is to his or her subjects in that archaeologists and anthropologists are more sensitive to the material culture of people — archaeologists particularly. In archaeological investigations, meaningful social patterns concerning certain objects can be revealed, indicating *attunement* to these objects. The manner in which a certain object type was spatially and temporally distributed in a society is one of the clearest indications of how the members of that society were *experiencing* these objects. These objects may then be used as external indices in modeling cognitive systems for the ancient inhabitants the archaeologist is investigating. Where attunement is in evidence, as I propose in the Bladen case study, archaeology can contribute uniquely to our understanding of cognition and in so doing provide archaeologists with a method for retrieving potential representations from the past.

I used a two-step process in constructing a formal model of a cognitive system in my research on Bladen exchange. An archaeologist wanting to elucidate the representations to which past people were subject can follow the same two-step process that I have used. This process is namely:

1. To infer cognitive attunement to some external index.

2. To construct a formal model describing a *credible* dynamical system in which the external index plays a role as a state or constraint of the dynamical system. (Often this second step takes some inference, as with the first step, but most of the time one can build on physical or economic models that are well established, and/or models that can be tested to some degree.)

It might seem circular that in order to elucidate the representations to which past people were subject, the archaeologist must first propose what people were thinking and then formally model it, for what good would modeling something be if we already knew what people thought? But the purpose of constructing a formal model of a cognitive system is not only to allow inferences to be made about what people thought about an external index, but to understand how people's thoughts related to the external index developed. This allows the archaeologist to compare a representation in different times of a society's history, and hence allows the archaeologist to formulate theories as to why this representation may have developed.

There is another reason why it is important to construct a formal model of a cognitive system. Representations are the building blocks for other representations and formal modeling is a means of accommodating more complex representations built on simpler representations. Let me use the Bladen case study to illustrate what I mean about building upon representations.

In the Bladen case study, I first inferred cognitive attunement to frequency of manos and metates and then I constructed a mathematical model of the dynamical system that described how the frequency of manos and metates changed through time. I could have stopped before constructing the model describing how frequency of manos and metates changed through time and ended after arguing that frequency of manos and metates had meaning for the Bladen inhabitants. However, by considering the frequency of manos and metates at three communities and treating the change in frequency of manos and metates as a dynamical system, I was able to propose the following: that the frequencies of manos and metates were indications of status, how status at the communities changed through time, and that the Bladen communities would have been ranked differently in the minds of the local people, provided that the inhabitants were aware of the importance of the frequencies of manos and metates. Thus, from the representation corresponding to the attunement to mano and metate frequency arose another representation, namely the representation of "marginal" standard of living at the communities (i.e. an emic cognitive ranking of the communities relative to each other).

As a discipline, archaeology has much to gain from a model of cognition in which supra-individual cognition plays a role, especially since much of the archaeological record can be viewed as a record of supra-individual or external indices to which individuals were attuned. As such, archaeology cannot afford *not* to be actively involved in researching and testing the model presented here. Archaeology can contribute to the model presented here by locating evidence which can help us gain insight into past peoples' perceptions. For example, in the case of the Bladen sites, archaeologists need to intensify excavations around the areas within the sites where iconography or textual information is more likely to be recovered reflecting the ancient Bladen inhabitants' perceptions of how the Bladen communities might have been ranked relative to each other (e.g. the stela plazas). Textual and iconographic evidence can help to inform a general model of cognition which can then be extended and applied to different archaeological contexts.

Concluding Statement: The Future for Cognitive Archaeology

The picture painted by this thesis is a world that is conceivably full of dynamical systems which may operate in many different aspects of social life. Each dynamical system can be seen to operate at a different scale. There are dynamical systems that involve the neurons of the brain; others operate between a person and an object; still others subsume larger social units such as communities. These dynamical systems (which of course must be assessed as such), if shown to constitute cognitive systems, can be conceived of as the bases of cognition. Cognitive systems are dynamical systems that generate representations and store these representations for the individual. All individuals can be conceived of as being tied to them irrevocably and they not only provide individuals with what they know but define who they are.

Reconstructing cognitive systems is important for archaeology because cognitive systems can be conceived of as bridges to understanding past peoples' mind frames, and mathematical description — being invariant through time and space — can be seen as a vehicle for crossing these bridges. The living human substrate which is required of a psychological approach is absent in archaeology. The cognitive approach which has been advocated in this thesis, however, permits cognition to be studied in just such a context as archaeology, in which the living human substrate is missing.

Glossary: Some Definitions Used in the Thesis

Attunement Perception, awareness, experience. To be attuned to something is to perceive something, to be aware of something, to experience something.

Cognition Cognition in anthropology has been defined in a number of related ways. Atran's (1990:3) use of cognition reflects the "... internal structure of ideas by which the world is conceptualized." D'Andrade's (1995:1) perspective is related but broader; he defines cognitive anthropology as "the study of the relation between human society and human thought." Moreover, D'Andrade (1995:1) states that the cognitive anthropological agenda is is closely linked to that of psychology. With regard to the term cognition, I will provide more than one definition relevant to my thesis, all of which are related:

1. Cognition refers to "the underlying mechanisms, states, and processes" responsible for one's actions and behavior (van Gelder and Port 1995:1). I would also add to this definition that one's actions and behavior commonly *constitute* these underlying mechanisms, states, and processes, and one's actions and behavior therefore

become integral in the emergence of cognition (see Thelen [1995] and Turvey and Carello [1995] for examples of this compelling reversal).

2. In more abstract terms, "cognition is the behavior of an appropriate kind of dynamical system" (van Gelder and Port 1995:10,11).
3. Because dynamical systems process information (Wellstead 1979), the above definition is consistent with the generally held conception among cognitive scientists that cognition is a system for processing *information* (Bourne *et al* 1986:2). Defined as such, *memory* can be seen to play a significant role in cognition mainly because it is integral for information processing.
4. Cognition also includes the so-called "higher mental processes" that are characteristic of human-grade cognition, like perception, language, decision-making, and distributed executive control. These cognitive capabilities, like the formation of memory, can be conceived of as the capabilities of certain kinds of dynamical systems (see Turvey and Carello [1995], Elman [1995], Townsend and Busemeyer [1995], and Reisberg [1997] and Donald [2002], respectively).

Although one can consider dynamical systems to be responsible for all of the cognitive capabilities that define what it is to have human-grade cognition, I will mainly concentrate on the information processing capability of dynamical systems, the distributed executive control of certain dynamical systems, and the perceptual capability of certain dynamical systems (see Chapter 7). There is considerable evidence to suggest that dynamical systems can potentially account for most if not all cognitive capabilities, as there is plenty of research which suggests it (see Turvey and Carello [1995], Elman [1995], Townsend and Busemeyer [1995], and Reisberg [1997] and Donald [2002], as well as my arguments in Section 3.5). However, this study focuses on the three above mentioned cognitive capabilities, expounds on them, and in so doing provides an initial framework for a more comprehensive model of cognition that allows these cognitive capabilities to be conceived of as operating in a supra-individual realm as well as in an embodied realm.

Dynamical System A system that changes through time (Hirsch 1984:3). Although *in general* many phenomena or processes can be conceived of as constituting dynamical systems in a loose sense, in order for *a particular* phenomenon or process to be identified as a dynamical system, the process or phenomenon in question must be formally modeled and analyzed (i.e. assessed) before it can be considered to constitute a *credible* dynamical system.

Environment Environment is a relative term I use to reflect the context in which an object is situated. For example, if the object of discussion is the individual, then the environment consists of the natural and social phenomena occurring outside of the individual. If the object of discussion is a neuron, then the environment comprises its linkages with other neurons in the nervous system.

Individual A body and a brain (i.e. a nervous system).

Information A pattern existent in the environment. Later in the thesis, "information" will specifically refer to a pattern in the values of the states of a dynamical system. This *pattern* can be the value of a dynamical system's state with respect to time (i.e. a trajectory of the dynamical system), or for dynamical systems with multiple states, the pattern can be the values of a dynamical system's states with respect to each other.

Information Processing The processes of storing information into memory and retrieving information from memory.

Memory Storage space which, though theoretically can manifest itself anywhere, is commonly regarded to be a brain function and therefore associated with the nervous system of the individual. Memory is essential for information processing and cognition cannot arise without memory.

Representations or beliefs Information that is meaningful to the brain though not necessarily generated by the brain. Thus, representations are essentially signs that have both a physical and objective component to them as well as phenomenological component to them (i.e. they are objects in the mind). However, unlike the conventional conception of signs which are taken to be arbitrary symbols that simply *instantiate*, representations are taken here to be situated in time and space and therefore *develop* through a process or, more specifically, through a dynamical system.

System A system is an interrelated "network of attributes or entities forming a complex whole" (Clarke 1978:43). The notion of a network described as a "whole" would imply that a system is *bounded* (van Gelder and Port 1995:5). Systems are mathematically describable.

Appendix A: Rock Descriptions in the Bladen Region

The following appendix contains rock descriptions of the source rock that was collected along the Bladen Branch from west to east.

Muklebal Valley:

MBT-2 Hydrothermal quartz on limestone.

MBT-3 Pinkish limestone conglomerate with lots of large white clasts.

MBT-6 White limestone. Extremely fine grained with little transparent crystals.

MBT-7 Pinkish coarse grained limestone with reworked fine grained limestone clasts.

MBT-12 Coarse grained pinkish-white limestone.

Ek Xux Valley:

EX-1 Volcanic rock with light grey matrix embedded with grey crystals and pyrite crystals. Heavily silicified.

EX-2 Volcanic rock. Holocrystaline quartz-syenite with pink/grey matrix and embedded with well defined pink feldspar and dark grey chunks. Heavily silicified.

EX-3 Volcanic rock. Holocrystaline quartz-syenite with green/grey matrix and embedded with pink feldspar and dark grey sulfides. Heavily silicified.

EX-4 Volcanic rock. Dark grey matrix with small-medium white phenocrysts. Moderate to heavy silicification.

EX-5 Volcanic rock with light grey matrix and purple tinge embedded with many small white crystals. Heavily silicified.

EX-6 Volcanic rock. Light pinkish-grey matrix with dark brown chunks and pink K-feldspar phenocrysts. Light to moderate silicification. Layered texture apparent.

EX-7 Volcanic rock with grey matrix and embedded with well defined pink feldspar and dark grey chunks. Heavily silicified.

EX-8 Volcanic rock. Light grey matrix with pink K-feldspar phenocrysts. Heavily silicified.

EX-9 Volcanic rock with green/grey matrix and embedded with pink feldspar and dark grey chunks. Heavily silicified.

EX-10 Volcanic rock. Pinkish-brown matrix embedded with pink feldspar and dark grey chunks. Heavily silicified.

EX-11 Volcanic rock with light grey matrix and purple tinge embedded with many small white quartz and feldspar crystals. Heavily silicified.

EX-12 Volcanic rock. Light green in color with mixed sized black sulfides, white quartz, and small pink K-feldspar phenocrysts. Some hemotite seepage apparent. Heavily silicified.

EX-13 Volcanic rock with dark grey matrix embedded with medium sized quartz and K-feldspar phenocrysts. Heavily silicified.

EX-14 Volcanic rock with green/grey matrix and embedded with pink feldspar and dark grey chunks. Heavily silicified.

EX-15 Volcanic/ hypabyssal rock with light grey matrix and purple tinge embedded with many small euhedral white quartz and K-feldspar crystals. Heavily silicified.

EX-16 Mylonitized volcanic rock with pinkish-grey matrix embedded with small-medium sized pink phenocrysts and black crystals. Heavily silicified with flow texture.

EX-17 Volcanic rock with K-feldspar and quartz in a red-black matrix. Moderately silicified. Layered texture is evident.

EX-18 Volcanic rock with pinkish-light grey matrix embedded with not easily defined white, black, and pink phenocrysts. Moderately silicified.

EX-19 Volcanic rock. Silicified welded tuff with grey matrix and puple tinge embedded with small white quartz, K-feldspar crystals. Heavily silicified.

EX-20 Volcanic rock. Dark grey matrix with large pink phenocrysts. Moderate silicification.

EX-21 Volcanic rock with light grey matrix embedded with grey crystals and pink feldspar crystals. Heavily silicified.

Cuyamel Valley:

C-1 Volcanic rock. Welded tuff. Purple banded dense grey matrix with feldspar phenocrysts. Contains quartz vein.

C-2 Volcanic rock. Grey matrix with lots of small-medium sized white and pink phenocrysts. Heavily silicified.

C-3 Volcanic rock. Welded tuff. Dense green/grey matrix with almost no phenocrysts.

C-4 Volcanic rock. Grey matrix with feldspar phenocrysts. Heavily silicified.

C-5 Volcanic rock. Dark greeen/grey matrix with a few lighter phenocrysts. Heavily silicified.

C-6 Volcanic rock. Volcanic ash. Dark grey matrix with medium-large pink feldspar phenocrysts. Heavily silicified.

C-7 Volcanic rock. Grey matrix with medium-large pink feldspar phenocrysts. Heavily silicified. Has a foliation and phyllitic sheen.

C-9 Volcanic rock. Welded tuff. Dense brownish-grey matrix with layers of different shades of black-red.

C-10 Volcanic rock. Welded tuff. Dense grey matrix with almost no phenocrysts.

C-11 Volcanic rock. Dark grey matrix with pink and white phenocrysts. Heavily silicified.

C-12 Volcanic rock. Sheared silicified grey matrix with brown phenocrysts. Heavily silicified.

Ramos Quebrada:

RHF-A Volcaniclastic rock. Fine grained rock that is grey in color but with iron oxide staining.

RHF-B Volcaniclastic rock. Medium grained rock that is grey with quartz crystals. Stained by iron oxide.

RHF-C Volcaniclastic rock. White and red in color with bands.

RHF-D Volcaniclastic rock. Grey small-medium grained.

RHF-E Siltstone. Light grey to black banding.

RQ-1 Coarse grained volcaniclastic rock. Small-medium grained. Contains quartz and hematite.

RQ-2 Volcanic rock. Grey matrix with white phenocrysts. Layers evident. Moderately silicified.

RQ-3 Volcanic rock. Grey matrix with white-pink phenocrysts and tiny black chunks. Heavily silicified.

RQ-4 Volcanic rock. Light grey matrix with white-pink phenocrysts that are not well defined. Heavily silicified.

RQ-5 Volcaniclastic rock. Fine grained rock that is grey in color but with iron oxide staining.

RQ-6 Black mudstone with medium sized pyrite crystals.

RQ-7 Coarse grained volcaniclastic rock. Contains large grains of quartz and black sulfides.

RQ-8 Volcanic/hypabyssal rock. Grey with pink K-feldspar phenocrysts. Bands present. Heavily silicified.

RQ-9 Volcanic rock. Grey matrix with white-pink phenocrysts that are not well defined. Heavily silicified.

RQ-10 Volcanic rock. Dark grey matrix with medium-large pink K-feldspar phenocrysts. Embedded with small dark glass fragments. Feldspar starting to weather.

RQ-11 Volcanic rock. Greenish-grey matrix with medium-large K-feldspar and some pyrite. Moderately silicified.

RQ-12 Volcanic rock. Light pink and grey matrix with white phenocrysts. Weakly silicified.

RQ-13 Volcanic rock. Greenish-grey matrix with K-feldspar and some pyrite. Heavily silicified.

RQ-14 Volcaniclastic rock. Fine grained rock that is light grey in color but with limonitic staining.

RQ-15 Volcanic rock. Dark grey matrix with small white phenocrysts. Layered texture evident. Heavily silicified.

RQ-16 Volcanic rock. Light grey matrix with tiny pyrite crystals and black impurities.

RQ-17 Volcanic rock. Light pink and green matrix. Small transparent phenocrysts. Heavily silicified.

RQ-18 Volcanic rock. Welded tuff with dark grey and black-red bands. Contains small white phenocrysts.

RQ-19 Volcanic rock. Silicified volcanic ash. Red matrix with small white phenocrysts and black sulfides. Heavily silicified.

Teakettle Camp:

TK-1 Volcanic rock. Pink and beige matrix with pink phenocrysts and some quartz crystals. Red in color. Moderately silicified.

TK-2 Volcanic rock. Holocrystaline quartz-syenite with green/grey matrix and embedded with white phenocrysts. Heavily silicified.

TK-3 Volcanic rock. Purple matrix with pink phenocrysts and small quartz crystals. Heavily silicified.

TK-4 Volcanic rock. Pinkish-grey matrix with white phenocrysts and some pyrite.

TK-5 Volcaniclastic rock. Medium grained rock that is grey in color but with iron oxide staining.

TK-6 Volcanic rock. Pinkish-grey matrix with white phenocrysts and some pyrite.

TK-7 Volcaniclastic rock. Medium grained rock that is grey in color but with black sulfides.

Quebrada de Oro:

QDO-A Volcanic rock. Grey matrix with white phenocrysts. Heavily silicified.

QDO-B Volcaniclastic rock. Fine grained rock that is grey in color but with iron oxide staining.

QDO-C Volcaniclastic rock. Quartz rich conglomerate.

QDO-D Volcanic rock. Pink and beige matrix with pink phenocrysts and some quartz crystals. Red in color. Moderately silicified.

QDO-E Black mudstone.

QDO-1 Volcaniclastic rock. Quartz rich conglomerate. Very large grain size.

QDO-2 Volcanic rock. Dark grey matrix with some small white phenocrysts. Heavily silicified.

QDO-5 Volcaniclastic rock. Fine grained rock that is grey in color but with iron oxide staining.

QDO-7 Red iron ore deposit.

QDO-9 Volcaniclastic rock. Fine-medium grained. Grey in color.

QDO-10 Volcanic rock. Heavily weathered leaving vesicles where phenocrysts used to be. Grey in color.

Richardson Creek Valley:

RC-3 Volcanic rock. Light green matrix with white medium sized phenocrystsof quartz and feldspar. Heavily silicified.

RC-4 Volcanic rock. Light green matrix with white small phenocrysts of quartz and feldspar. Heavily silicified.

Forest Hill Camp

FH-1 Volcanic rock. Green matrix with large pink phenocrysts and dark green phenocrysts. Weakly silicified.

FH-2 Volcanic rock. Whiteish-cream colored matrix with black impurities. Heavily silicified.

FH-3 Volcanic rock. Light grey matrix with small black sulfides and quartz crystals. Iron oxide staining is present. Weakly silicified.

FH-4 Volcanic rock. Pale green matrix with medium sized white phenocrysts.

FH-5 Volcanic rock. Welded tuff that has red, white, and black bands with small black sulfides. Moderately silicified.

FH-6 Volcanic rock. Grey matrix with large white phenocrysts. Moderately silicified.

FH-7 Volcanic rock. Welded tuff that has black and purple bands with tiny white phenocrysts. Heavily silicified.

FH-8 Volcanic rock. Grey matrix with tiny black and white crystals and pyrite crystals. Contains light grey bands. Heavily silicified.

FH-9 Volcanic rock. Grey matrix with medium sized black crystals and pyrite crystals. Heavily silicified.

FH-10 Volcanic rock. Grey matrix with tiny black crystals and pyrite crystals. Heavily silicified.

FH-11 Volcanic rock. Heavily weathered. Dark grey with white phenocrysts, many of which have turned red due to weathering.

FH-12 Volcanic rock. Pale green matrix with tiny white and black phenocrysts.

FH-13 Volcanic rock. Beige matrix with black and brown broad bands. Highly silicified.

FH-14 Volcanic rock. Grey matrix with small white and pink phenocrysts. Moderately silicified.

FH-15 Volcanic rock. Grey matrix with tiny black and white crystals and pyrite crystals. Heavily silicified.

FH-16 Volcanic rock. Grey matrix with tiny black and white crystals and pyrite crystals. Moderately silicified.

FH-17 Volcanic rock. Grey matrix with tiny black crystals and pyrite crystals. Heavily silicified.

FH-18 Vocaniclastic rock. Fine-medium grained conglomerate. Grey in color.

FH-19 Volcanic rock. Dark green matrix with large pink phenocrysts and dark green phenocrysts. Weakly silicified.

FH-20 Volcanic rock. Grey matrix with small white phenocrysts. Moderately silicified.

Appendix B: Photographs of Rock/Artifact Comparisons

The following appendix contains photographic examples of the hand sample comparison that was conducted.

Figure 24: Siltstone source rock with artifact.

Figure 25: Volcanic source rock with artifact.

Figure 26: Hypabyssal source rock with artifact.

Figure 27: Volcaniclastic source rock with artifact.

Appendix C: Petrographic Analysis of Bladen Artifacts

The following appendix contains charts displaying the results of hand-sample and thin-section petrography with associated confidence levels. The confidence scheme was based on a ranking system from 0 to 10. In this system:

- 10 indicated that a perfect match for the artifact was found in the source rock collection for a specific valley, with no close matches in the other valleys.
- 8 indicated that a perfect match for the artifact was found in the source rock collection for a specific valley.
- 6 indicated that a close match for the artifact was found in the source rock collection for a specific valley, with no other close matches in the other valleys.
- 4 indicated that a close match for the artifact was found in the source rock collection for a specific valley.
- 2 indicated that no close matches for an artifact in the source rock collection were found. However, according to the geology of the Bladen Branch, a specific source for the artifact could be inferred.

- 0 indicated that no specific source for the artifact was known.

Note that the prefix *QDO* refers to mano and metate samples collected at the Quebrada de Oro Ruin, the prefix *RHF* refers to mano and metate samples collected at the RHF Site, the prefixes *EK*, *EXRM*, *EXHM* refer to mano and metate samples collected at Ek Xux, and the prefixes *MU* and *MBT* refer to mano and metate samples collected at Muklebal Tzul.

Artifact	Source Match (from best to worst)	Prov.	Conf.	Description
QDO-1	RQ-1, QDO-C	QDO	4	Coarse grained volcaniclastic rock.
QDO-2	QDO-5, QDO-B, RQ-14	QDO	8	Fine grained volcaniclastic rock.
QDO-3	QDO-A, RQ-3, C-6, EX-7	QDO	8	Volcanic rock.
QDO-4	TK-5, RQ-1 (no good examples)	QDO	2	Medium grained volcaniclastic.
QDO-5	RHF-D, QDO-D, QDO-5	QDO	8	Fine-medium grained volcaniclastic rock.
QDO-6	RQ-1, QDO-C	QDO	8	Coarse grained volcaniclastic rock.
QDO-6A	RQ-1, QDO-C	QDO	8	Coarse grained volcaniclastic rock.
QDO-8	RC-4, PEXPI-1	QDO	2	Weakly silicified volcanic rock.
QDO-9	QDO-E	QDO	8	Black mudstone.
QDO-10	EX-5, EX-19	EX	4	Highly silicified volcanic rock.
QDO-11	QDO-5, QDO-B, RQ-14	QDO	8	Fine grained volcaniclastic rock.
QDO-11A	QDO-5, QDO-B, RQ-14	QDO	8	Fine grained volcaniclastic rock.
QDO-12	NONE	QDO	2	Extremely fine grained volcaniclastic rock. Similar to QDO-5 and QDO-B but smaller grain size.
QDO-14	QDO-5, QDO-B, RQ-14	QDO	4	Fine grained volcaniclastic rock. Red in color.
QDO-15	TK-5, RQ-7, QDO-C	QDO	2	Medium grained volcaniclastic rock.
QDO-16	RC-4	QDO	2	Weakly silicified volcanic rock.
QDO-17	QDO-5, QDO-B, RQ-14	QDO	8	Fine grained volcaniclastic rock embedded with chunks.
QDO-18	QDO-C, RQ-1	QDO	8	Coarse grained volcaniclastic rock. Red in color.
QDO-19	QDO-5, QDO-B, RQ-14	QDO	8	Fine grained volcaniclastic rock.
QDO-20	QDO-B, RQ-14	QDO	4	Fine-medium grained volcaniclastic rock.
QDO-21	QDO-B, RQ-14	QDO	2	Fine grained volcaniclastic rock embedded with chunks.
QDO-22	QDO-B, RQ-14	QDO	2	Fine-medium grained volcaniclastic rock embedded with chunks.
QDO-23	QDO-E	QDO	8	Black mudstone.
QDO-24	FH-1	FH	10	Pale green volcanic rock with pink phenocrysts.
QDO-25	QDO-5, QDO-B, RQ-14	QDO	8	Fine grained volcaniclastic rock.
QDO-F	QDO-5, QDO-B, RQ-14	QDO	8	Fine grained volcaniclastic rock.

Artifact	Source Match (from best to worst)	Prov.	Conf.	Description
RHF-1	RQ-14, RHF-A, QDO-5, QDO-B	RQ	8	Fine grained volcaniclastic rock.
RHF-2	RQ-7, RQ-1, QDO-C	RQ	8	Coarse grained volcaniclastic rock.
RHF-3	RQ-14, RHF-A, QDO-5, QDO-B	RQ	8	Fine grained volcaniclastic rock.
RHF-4	RQ-14, RHF-A, QDO-5, QDO-B	RQ	8	Fine grained volcaniclastic rock.
RHF-5	RQ-4, TK-7	RQ	6	Volcanic rock with small white phenocrysts.
RHF-6	RHF-D/A	RQ	2	Medium grained volcaniclastic rock. Red in color.
RHF-7	RQ-14, RHF-A, QDO-5, QDO-B	RQ	8	Fine grained volcaniclastic rock.
RHF-8	RHF-D/A	RQ	2	Medium-large grained volcaniclastic rock.
RHF-9	RHF-A	RQ	10	Fine grained volcaniclastic rock.
RHF-10	RHF-B, RQ-1	RQ	8	Medium-large grained volcaniclastic rock.
RHF-11	RQ-7, RQ-1, QDO-C	RQ	8	Coarse grained volcaniclastic rock. Red in color.
RHF-12	RQ-14, RHF-A, QDO-5, QDO-B	RQ	8	Fine grained volcaniclastic rock. Red in color.
RHF-13	RHF-D	RQ	10	Fine-medium grained volcaniclastic rock. Red in color.
RHF-14	RQ-14, RHF-A, QDO-5, QDO-B	RQ	8	Fine grained volcaniclastic rock.
RHF-15	RQ-1/RHF-D	RQ	8	Medium grained volcaniclastic rock. Red in color.
RHF-16	NONE	RQ	2	Coarse grained volcaniclastic rock.
RHF-17	RHF-D	RQ	10	Fine-medium grained volcaniclastic rock. Red in color.
RHF-18	RQ-1/RQ-7, QDO-C	RQ	4	Medium grained volcaniclastic rock.
RHF-19	RHF-D	RQ	10	Fine-medium grained volcaniclastic rock. Red in color.
RHF-20	RHF-D	RQ	6	Medium grained volcaniclastic rock.
RHF-21	NONE	RQ	2	Volcanic rock.
RHF-22	RHF-B/D	RQ	8	Fine-medium grained volcaniclastic rock.
RHF-23	RQ-7, RQ-1, QDO-C	RQ	8	Large grained volcaniclastic rock.
RHF-24	RHF-E	RQ	6	Mudstone or siltstone.
RHF-25	NONE	NONE	0	Vesicular basalt.
RHF-26	RHF-A, RQ-5	RQ	10	Fine grained volcaniclastic rock.

Artifact	Source Match (from best to worst)	Prov.	Con.	Description
EK-1	RQ-7/5	RQ/QDO	2	Medium grained volcaniclastic rock.
EK-2	NONE	NONE	0	Vesicular Basalt.
EK-3	QDO-B, QDO-5	RQ/QDO	2	Fine grained volcaniclastic rock. Red in color.
EK-4	RC-4	EX	2	Weakly silicified volcanic rock with white phenocrysts.
EK-5	NONE	NONE	0	Fine grained metamorphic rock.
EK-6	QDO-B, QDO-5	RQ/QDO	2	Fine grained volcaniclastic rock. Red in color.
EK-7	FH-18, RHF-B/RQ-1	RQ-FH	2	Fine-medium grained volcaniclastic rock.
EK-8	FH-18, RHF-B/RQ-1	RQ-FH	2	Fine-medium grained volcaniclastic rock.
EK-9	FH-18, RHF-B/RQ-1	RQ-FH	2	Fine-medium grained volcaniclastic rock.
EK-10	FH-18, RHF-B/RQ-1	RQ-FH	2	Fine-medium grained volcaniclastic rock.
EK-11	QDO-E	MUK	2	Black mudstone.
EK-12	NONE	EX	2	Weakly silicified volcanic rock with medium sized dark phenocrysts. Buff in color.
EK-13	RC-4	EX	2	Weakly silicified volcanic rock with white phenocrysts.
EK-14	NONE	EX	2	Weakly silicified volcanic rock with medium sized dark phenocrysts. Buff in color.
EK-15	NONE	EX	2	Weakly silicified volcanic rock with medium sized dark phenocrysts. Buff in color.
EK-16	RHF-C	RQ/QDO	2	Medium-large grain volcaniclastic rock. Red in color.
EK-17	RQ-12	RQ/QDO	2	Volcanic rock. Welded tuff.
EK-18	NONE	EX	2	Silicified volcanic rock. Buff in color.
EK-19	QDO-E	MUK	2	Black mudstone.
EK-20	NONE	EX	2	Volcanic rock.
EK-21	RHF-D, QDO-C	RQ/QDO	2	Medium grained volcaniclastic rock. Red in color.
EK-22	NONE	EX	2	Volcanic rock.
EK-23	EX-19, EX-11	EX	8	Highly silicified volcanic rock with small white phenocrysts.
EK-24	QDO-B, QDO-5	RQ/QDO	2	Fine grained volcaniclastic rock. Red in color.
EK-25	EX-19, EX-11	EX	8	Highly silicified volcanic rock with small white phenocrysts.
EK-26	QDO-B, QDO-5	RQ/QDO	2	Fine grained volcaniclastic rock. Red in color.
EXRM-M2	NONE	EX	2	Volcanic welded tuff.
EXRM-MT2	NONE	RQ/QDO	2	Coarse grained volcaniclastic rock.
EXRM-M1	NONE	RQ/QDO	2	Fine grained volcaniclastic rock.
EXRM-MT1	NONE	RQ/QDO	2	Medium grained volcaniclastic rock.
EXHM-M1	NONE	RQ/QDO	2	Coarse grained volcaniclastic rock with large quartz crystals.
EXHM-MT1	NONE	EX	2	Volcanic welded tuff.

Artifact	Source Match (from best to worst)	Prov.	Con.	Description
MU-1	NONE	NONE	0	Vesicular basalt.
MU-2	TK-5, RHF-D	RQ/QDO	2	Fine-medium grained volcaniclastic rock.
MU-3	QDO-E	MUK	2	Black mudstone.
MU-4	NONE	RQ/QDO	2	Volcaniclastic.
MU-5	TK-5, RQ-5	RQ/QDO	2	Very fine grained volcaniclastic rock.
MU-6	QDO-E	MUK	2	Black mudstone.
MU-7	RQ-7	RQ/QDO	2	Medium grained volcaniclastic rock with lots of quartz.
MU-8	RHF-D, B, QDO-C	RQ/QDO	2	Medium-coarse grained volcaniclastic rock. Red in color.
MU-9	QDO-E	MUK	2	Black mudstone.
MU-10	TK-5, RHF-D	RQ/QDO	2	Fine -medium grained volcaniclastic rock. Red in color.
MU-11	TK-5, RHF-D	RQ/QDO	2	Fine -medium grained volcaniclastic rock. Red in color.
MU-12	RQ-5, RHF-A	RQ/QDO	2	Fine grained volcaniclastic rock with a few small pyrite crystals.
MU-13	RQ-5, RHF-A	RQ/QDO	2	Fine grained volcaniclastic rock with a few small pyrite crystals.
MU-14	NONE	NONE	0	Vesicular basalt.
MU-15	QDO-E	MUK	2	Black mudstone.
MU-16	TK-5, RQ-5	RQ/QDO	2	Very fine grained volcaniclastic rock.
MU-17	RHF-A, QDO-B, QDO-5	RQ/QDO	2	Fine grained volcaniclastic. Red in color.
MU-18	QDO-5, QDO-B, RHF-A	RQ/QDO	2	Fine grained volcaniclastic. Red in color.
MU-19	NONE	EX/C	2	Volcanic rock. Welded tuff.
MU-20	QDO-E	MUK	2	Black mudstone.
MU-21	QDO-5, QDO-B	RQ/QDO	2	Fine grained volcaniclastic rock. Red in color.
MU-22	QDO-5, QDO-B	RQ/QDO	2	Fine grained volcaniclastic rock. Red in color.
MU-23	RC-4, FH-4	EX	2	Weakly silicified volcanic rock with white phenocrysts.
MU-24	NONE	NONE	0	Vesicular basalt.
MU-25	QDO-E	MUK	2	Black mudstone.
MU-26	QDO-E/RHF-E	MUK	2	Mudstone or siltstone.
MU-27	EX-6, C1/C10	EX/C	2	Volcanic rock. Welded tuff. Pink in color.
MU-28	C1/C10	EX/C	2	Volcanic rock. Welded tuff. Grey in color.
MBT-5(MT-1)	TK-5, RHF-A	RQ/QDO	2	Fine-medium grained volcaniclastic rock.
MBT(M-5)	QDO-5,B, RQ-5	RQ/QDO	2	Fine grained volcaniclastic rock. Red in color.
MBT-11(M-1)	NONE	RQ/QDO	2	Fine grained volcaniclastic.
MBT-9(M-2)	RQ-7, RQ-1, QDO-C	RQ/QDO	2	Coarse grained volcaniclastic rock. Red in color.

Appendix D: Geological Descriptions of Artifacts at Sites Linked to the Bladen Sites

The following appendix contains rock descriptions of the ground stone artifacts that were collected from the Department of Archaeology, Belize, which have links to the Bladen sites.

Altun Ha:

RP-715 Weathered pink granite.

RP-570 Granite.

35/196-1:363(RP-690) Vesicular basalt.

35/196-1:252(RP-68/88) Weathered pink granite.

RP-460 Hard limestone.

35/196-1:364 Vesicular basalt.

35/196-1:243(FS-15) Pink granite.

RP-103 Red granite.

RP-472 Grey granite.

35/196-1:241 Weathered granite.

35/196-1:364(RP-703) Fine-grained Bladen volcaniclastic (RQ/QDO)

35/196-1:241F(RP-43) Pink granite.

35/196-1:241D(RP-43) Bladen volcanic (EX).

RP-472B Pink granite.

RP-457 Granite.

RP-412(3) Vesicular basalt.

RP-472(9) Basalt (like BP-O).

35/196-1:241B(RP-43) Pink granite.

35/196-1:328(9)(RP-388) Pink limestone.

RP-91 Vesicular basalt.

35/196-1:304(RP-103) Metamorphic.

35/196-1:241G(RP-43) Vesicular basalt.

RP-415 Pink limestone.

RP-472(1) Badly weathered granite.

35/196-1:241C(RP-43) Bladen volcaniclastic (RQ/QDO).

35/196-1:208 Pink granite.

35/196-1:239(RP-33) Vesicular basalt.

35/196-1:241A Vesicular basalt.

35/196-1:241E(RP-43) Badly weathered limestone (chem.modified).

RP-472 Vesicular basalt.

35/196-1:223(RP-12) Vesicular basalt.

35/196-1:249(RP-91) Fine-grained Bladen volcaniclastic (RQ/QDO).

Baking Pot:

28/190-1:52J Pink granite.

28/190-1:52V Pink granite.

28/190-1:52T Badly weathered fine-grained pink granite.

28/190-1:52M Badly weathered granite.

28/190-1:52F Badly weathered pink granite.

28/190-1:52K Badly weathered pink granite.

28/190-1:52H Quartzite.

28/190-1:52L Badly weathered pink granite.

28/190-1:52E Badly weathered pink granite.

28/190-1:52I Pink quartzite.

28/190-1:52N Badly weathered pink granite.

28/190-1:52W Grey granite.

28/190-1:52G Bladen volcaniclastic (RQ/QDO).

28/190-1:52U Badly weathered Bladen Volcanic (EX).

28/190-1:52B Pink granite.

28/190-1:52A Pink granite.

28/190-1:52C Weathered granite.

28/190-1:52D Bladen volcaniclastic (RQ/QDO).

28/190-1:52Q Pink granite.

28/190-1:52O Badly weathered Bladen volcanic (EX).

28/190-1:52P Pink granite.

28/190-1:52S Pink granite.

28/190-1:52R Badly weathered pink granite.

Caledonia:

28/186-2:38B Bladen volcaniclastic (RQ/QDO).

28/186-2:38C Vesicular basalt.

28/186-2:38 Bladen volcanic (EX).

Xunantunich:

27/189-1:10 Quartzite.

27/189-1:13 Red granite.

27/189-1:151 Bladen volcaniclastic (RQ/QDO).

27/189-1:131 Pink granite.

27/189-1:273 Travertine.

27/189-1:11 Limestone.

27/189-1:135 Weathered pink granite.

27/189-1:5 Limestone.

27/189-1:150 Karstic crust (limestone).

27/189-1:137 Red granite.

27/189-1:134 Pink granite.

Appendix E: Mathematical Analysis of Bladen Exchange System

The following appendix is a cursory analysis of Equations 6.7 - 6.9. The result of this analysis has yielded eight cases and has identified an equilibrium in each case. Only Equilibrium II affects my system, however. The equations were analyzed using *Maple*.

```
> # Before I begin this analysis there exists a global condition that
> holds for all equilibria that are analyzed below and that condition is
> that (x1,x2,x3)>=0.  The reason for this condition is that x1, x2, and
> x3 denote frequencies of manos and metates which must be nonnegative.
> In addition to this global condition on the equilibria, there is a
> local condition that holds for each individual equilibrium.
>
> #--------------------------Equilibrium I--------------------------
> # Local Condition:
> # x1 < theta
> # x2 < theta
```

```
> # x3 < theta
> # Equations:
> # x1' = -A*x1+(k11+k1i)*r*x1+k12*r*x2+k13*r*x3
> # x2' = -A*x2+k21*r*x1+(k22+k2i)*r*x2+k23*r*x3
> # x3' = -A*x3+k32*r*x2+(k33+k3i)*r*x3
> #
> unassign('k11','k12','k13','k21','k22','k23','k31','k32','k33','k1i','
> k2i','k3i','A','x1','x2','x3',r);
> #Solving x1'=0,x2'=0,x3'=0
>
> simplify(solve({-A*x1+(k11+k1i)*r*x1+k12*r*x2+k13*r*x3=0,-A*x2+k21*r*x
> 1+(k22+k2i)*r*x2+k23*r*x3=0,-A*x3+k32*r*x2+(k33+k3i)*r*x3=0},{x1,x2,x3
> }));

                        {x2 = 0, x3 = 0, x1 = 0}

>
> # Equilibrium I always exists since the equilibrium (x1,x2,x3)=(0,0,0)
> and our condition for the equilibrium's existence is
> (x1,x2,x3)<theta=2,
>
> #------------------------Equilibrium II------------------------------
> # Local Condition:
> # x1 >= theta
> # x2 >= theta
> # x3 >= theta
> # Equations:
```

```
> # x1' = -A*x1+(k11+k1i)*r*theta+k12*r*theta+k13*r*theta
> # x2' = -A*x2+k21*r*theta+(k22+k2i)*r*theta+k23*r*theta
> # x3' = -A*x3+k32*r*theta+(k33+k3i)*r*theta
> #
> #Solving x1'=0,x2'=0,x3'=0
> unassign('k11','k12','k13','k21','k22','k23','k31','k32','k33','k1i','
> k2i','k3i','A','x1','x2','x3','r','theta');
> simplify(solve({-A*x1+(k11+k1i)*(r*theta)+k12*(r*theta)+k13*(r*theta)=
> 0,-A*x2+k21*(r*theta)+(k22+k2i)*(r*theta)+k23*(r*theta)=0,-A*x3+k32*(r
> *theta)+(k33+k3i)*(r*theta)=0},{x1,x2,x3}));

      r theta (k11 + k1i + k12 + k13)
{x1 = -------------------------------,
                     A

           r theta (k32 + k33 + k3i)
      x3 = -------------------------,
                       A

           r theta (k21 + k22 + k2i + k23)
      x2 = -------------------------------}
                          A

>
> k11:=7/116:
> k1i:=3/116:
> k12:=4/116:
```

```
> k13:=18/116:
> k21:=2/116:
> k22:=12/116:
> k2i:=2/116:
> k23:=16/116:
> k31:=0/116:
> k32:=1/116:
> k33:=50/116:
> k3i:=1/116:
> A:=0.23:
> r:=1.5:
> theta:=2.0:
>
> # Solving for the equilibrium using the middle of the range r
> solve({x2 = r*theta*(k21+k22+k23+k2i)/A, x1 =
> r*theta*(k11+k12+k13+k1i)/A, x3 = r*theta*(k32+k33+k3i)/A});

        {x1 = 3.598200900, x3 = 5.847076461, x2 = 3.598200900}

> unassign('r');
> # Solving for the equilibrium for the entire range of r
> solve({x2 = r*theta*(k21+k22+k23+k2i)/A, x1 =
> r*theta*(k11+k12+k13+k1i)/A, x3 =
> r*theta*(k32+k33+k3i)/A},{x1,x2,x3});

     {x1 = 2.398800600 r, x3 = 3.898050974 r, x2 = 2.398800600 r}
```

```
> #
> #
> ######  Analysis for Existence:
> ###### In order for Equilibrium II to exist, x1, x2, and x3 must
> satisfy the local condition for this equilibrium so that:
> (3.898050974*r, 2.398800600*r, 2.398800600*r)>theta=2.  Solving for r
> for x1 and x2, and x3 we get:

> solve(2.398800600*r>=2);

                  RealRange(.8337499999, infinity)

> solve(3.898050974*r>=2);

                  RealRange(.5130769231, infinity)

>
>
> ### The intersection of these sets, namely [.8337499999,infinity),
> then, is a sufficient condition for ensuring the existence of this
> equilibrium. Clearly, our range of [1,2] satisfies this condition so
> that we should expect this equilibrium.
>
>
> #####     Stability Analysis:
>
> unassign('r');
```

```
>
> f:=(x1,x2,x3)->-A*x1+(k11+k1i)*(r*theta)+k12*(r*theta)+k13*(r*theta):
> g:=(x1,x2,x3)->-A*x2+k21*(r*theta)+(k22+k2i)*(r*theta)+k23*(r*theta):
> h:=(x1,x2,x3)->-A*x3+k32*(r*theta)+(k33+k3i)*(r*theta):
> pts:=solve({f(x1,x2,x3)=0,g(x1,x2,x3)=0,h(x1,x2,x3)=0},{x1,x2,x3});

 pts := {x1 = 2.398800600 r, x3 = 3.898050974 r, x2 = 2.398800600 r}

> with(linalg):
> jac:=jacobian([f(x1,x2,x3),g(x1,x2,x3),h(x1,x2,x3)],[x1,x2,x3]);

                          [-.23      0        0  ]
                          [                      ]
                   jac := [ 0       -.23      0  ]
                          [                      ]
                          [ 0        0      -.23]

>
> eigenvals(subs(pts[1],eval(jac)));

               -.2300000000, -.2300000000, -.2300000000

> # Since the eigenvalues are negative Equilibrium II is stable for all
> r.
>
>
> #--------------------Equilibrium III----------------------
```

```
> #
> # x1 >= theta
> # x2 >= theta
> # x3 < theta
> #
> # x1' = -A*x1+(k11+k1i)*r*theta+k12*r*theta+k13*r*x3
> # x2' = -A*x2+k21*r*theta+(k22+k2i)*r*theta+k23*r*x3
> # x3' = -A*x3+k32*r*theta+(k33+k3i)*r*x3
> #
> #Solving x1'=0,x2'=0,x3'=0
> unassign('k11','k12','k13','k21','k22','k23','k31','k32','k33','k1i','
> k2i','k3i','A','x1','x2','x3','r','theta');
> simplify(solve({-A*x1+(k11+k1i)*(r*theta)+k12*(r*theta)+k13*r*x3=0,-A*
> x2+k21*(r*theta)+(k22+k2i)*(r*theta)+k23*r*x3=0,-A*x3+k32*(r*theta)+(k
> 33+k3i)*r*x3=0},{x1,x2,x3}));

               k32 r theta
  {x3 = - -------------------, x2 = r theta (-k21 A + k21 r k33
           -A + r k33 + r k3i

         + k21 r k3i - k22 A + r k22 k33 + r k22 k3i - k2i A

         + r k2i k33 + r k2i k3i - k23 r k32)/(A (-A + r k33 + r k3i)

        ), x1 = r theta (-k11 A + r k11 k33 + r k11 k3i - k1i A

         + r k1i k33 + r k1i k3i - k12 A + k12 r k33 + k12 r k3i
```

```
        - k13 r k32)/(A (-A + r k33 + r k3i))}

> k11:=7/116:
> k1i:=3/116:
> k12:=4/116:
> k13:=18/116:
> k21:=2/116:
> k22:=12/116:
> k2i:=2/116:
> k23:=16/116:
> k31:=0/116:
> k32:=1/116:
> k33:=50/116:
> k3i:=1/116:
> A:=0.23:
> r:=1.5:
> theta:=2:
>
> unassign('r');
> solve({x3 = -k32*r*theta/(-A+r*k33+r*k3i), x2 =
> r*theta*(-k21*A+k21*r*k33+k21*r*k3i-k22*A+r*k22*k33+r*k22*k3i-k2i*A+r*
> k2i*k33+r*k2i*k3i-k23*r*k32)/(A*(-A+r*k33+r*k3i)), x1 =
> r*theta*(-k11*A+r*k11*k33+r*k11*k3i-k1i*A+r*k1i*k33+r*k1i*k3i-k12*A+k1
> 2*r*k33+k12*r*k3i-k13*r*k32)/(A*(-A+r*k33+r*k3i))},{x1,x2,x3});

                                            10                   11
```

```
                  -6 r (-.6708333331 10   + .1250000000 10   r)
 {x1 = .1043478261 10   ------------------------------------------,
                                    -667. + 1275. r


       x2 =

                                        13                  13
                  -9 r (-.2668000000 10   + .5000000000 10   r)
       .2998500750 10   ------------------------------------------,
                                    -667. + 1275. r


                  r
       x3 = -50. ---------------}
                 -667. + 1275. r

> ##
> #### Analysis for Existence:
>
> ## r satisfies local conditions when:
>
> solve(.1043478261e-6*r*(-6708333331.+.1250000000e11*r)/(-667.+1275.*r)
> >=2);

 RealRange(.5182569724, Open(.5231372549)),

       RealRange(1.973409694, infinity)
```

```
> solve(.2998500750e-9*r*(-.2668000000e13+.5000000000e13*r)/(-667.+1275.
> *r)>=2);

  RealRange(.5185483756, Open(.5231372549)),

        RealRange(1.715901624, infinity)

> solve(-50.*r/(-667.+1275.*r)<2);

  RealRange(-infinity, Open(.5130769231)),

        RealRange(Open(.5231372549), infinity)

>
>
> ## r satisfies global conditions when:
>
> solve(.1043478261e-6*r*(-6708333331.+.1250000000e11*r)/(-667.+1275.*r)
> >=0);

  RealRange(0, Open(.5231372549)), RealRange(.5366666665, infinity)

> solve(.2998500750e-9*r*(-.2668000000e13+.5000000000e13*r)/(-667.+1275.
> *r)>=0);

  RealRange(0, Open(.5231372549)), RealRange(.5336000000, infinity)
```

```
> solve(-50.*r/(-667.+1275.*r)>=0);

                  RealRange(0, Open(.5231372549))

> # The intersection of these sets is empty and hence we should not
> expect an Equilibrium III for any r.
>
>
>
> #-------------------------Equilibrium IV-----------------------------
> #
> # x1 >= theta
> # x2 < theta
> # x3 >= theta
> #
> # x1' = -A*x1+(k11+k1i)*r*theta+k12*r*x2+k13*r*theta
> # x2' = -A*x2+k21*r*theta+(k22+k2i)*r*x2+k23*r*theta
> # x3' = -A*x3+k32*r*x2+(k33+k3i)*r*theta
> #
> #Solving x1'=0,x2'=0,x3'=0
> unassign('k11','k12','k13','k21','k22','k23','k31','k32','k33','k1i','
> k2i','k3i','A','x1','x2','x3','r','theta');
> simplify(solve({-A*x1+(k11+k1i)*(r*theta)+k12*r*x2+k13*(r*theta)=0,-A*
> x2+k21*(r*theta)+(k22+k2i)*r*x2+k23*(r*theta)=0,-A*x3+k32*r*x2+(k33+k3
> i)*(r*theta)=0},{x1,x2,x3}));

         r theta (k21 + k23)
```

```
{x2 = - -------------------, x3 = r theta (-k32 r k21 - k23 r k32
         -A + r k22 + r k2i

        - k33 A + r k22 k33 + r k2i k33 - k3i A + r k22 k3i

        + r k2i k3i)/(A (-A + r k22 + r k2i)), x1 = r theta (-k11 A

        + r k11 k22 + r k11 k2i - k1i A + r k1i k22 + r k1i k2i

        - k12 r k21 - k12 r k23 - k13 A + k13 r k22 + k13 r k2i)/(

       A (-A + r k22 + r k2i))}

>
> k11:=7/116:
> k1i:=3/116:
> k12:=4/116:
> k13:=18/116:
> k21:=2/116:
> k22:=12/116:
> k2i:=2/116:
> k23:=16/116:
> k31:=0/116:
> k32:=1/116:
> k33:=50/116:
> k3i:=1/116:
> A:=0.23:
```

```
> r:=1.5:
> theta:=2:
>

> unassign('r');
> solve({x1 =
> r*theta*(-k11*A+r*k11*k22+r*k11*k2i-k1i*A+r*k1i*k22+r*k1i*k2i-k12*r*k2
> 1-k12*r*k23-k13*A+k13*r*k22+k13*r*k2i)/(A*(-A+r*k22+r*k2i)), x3 =
> -r*theta*(r*k32*k21+k23*r*k32+A*k33-r*k22*k33-r*k2i*k33+A*k3i-r*k22*k3
> i-r*k2i*k3i)/(A*(-A+r*k22+r*k2i)), x2 =
> -r*theta*(k21+k23)/(-A+r*k22+r*k2i)},{x1,x2,x3});

                                            11                   11
                      -7 r (.1500000000 10    r - .2932500001 10   )
  {x3 = .8695652174 10   ---------------------------------------,
                                         -667. + 350. r

      x1 =

                                             13                 13
                      -9 r (-.4668999999 10    + .2000000000 10   r)
      .2998500750 10   ----------------------------------------,
                                          -667. + 350. r

                        r
      x2 = -900. --------------}
                 -667. + 350. r
```

```
>

>
> #### Analysis for Existence:
>
> ## r satisfies local conditions when:
>
> solve(.2998500750e-9*r*(-.4668999999e13+.2000000000e13*r)/(-667.+350.*
> r)>=2);

  RealRange(.8337500001, Open(1.905714286)),

        RealRange(2.667999999, infinity)

> solve(-900.*r/(-667.+350.*r)<2);

  RealRange(-infinity, Open(.8337500000)),

        RealRange(Open(1.905714286), infinity)

> solve(.8695652174e-7*r*(.1500000000e11*r-.2932500001e11)/(-667.+350.*r
> )>=2);

  RealRange(.5182569721, Open(1.905714286)),

        RealRange(1.973409695, infinity)
```

```
>
>
> ## r satisfies global condition when:
>
> solve(.2998500750e-9*r*(-.4668999999e13+.2000000000e13*r)/(-667.+350.*
> r)>=0);

  RealRange(0, Open(1.905714286)), RealRange(2.334500000, infinity)

> solve(-900.*r/(-667.+350.*r)>=0);

                  RealRange(0, Open(1.905714286))

> solve(.8695652174e-7*r*(.1500000000e11*r-.2932500001e11)/(-667.+350.*r
> )>=0);

  RealRange(0, Open(1.905714286)), RealRange(1.955000001, infinity)

> # The intersection of these sets is 0 and hence we should not expect
> an Equilibrium IV for any r.
>
>
>
>
> #-------------------------Equilibrium V-------------------------
> #
```

```
> # x1 < theta
> # x2 >= theta
> # x3 >= theta
> #
> # x1' = -A*x1+(k11+k1i)*r*x1+k12*r*theta+k13*r*theta
> # x2' = -A*x2+k21*r*x1+(k22+k2i)*r*theta+k23*r*theta
> # x3' = -A*x3+k32*r*theta+(k33+k3i)*r*theta
> #
> #Solving x1'=0,x2'=0,x3'=0
> unassign('k11','k12','k13','k21','k22','k23','k31','k32','k33','k1i','
> k2i','k3i','A','x1','x2','x3','r','theta');
> simplify(solve({-A*x1+(k11+k1i)*r*x1+k12*(r*theta)+k13*(r*theta)=0,-A*
> x2+k21*r*x1+(k22+k2i)*(r*theta)+k23*(r*theta)=0,-A*x3+k32*(r*theta)+(k
> 33+k3i)*(r*theta)=0},{x1,x2,x3}));

             r theta (k12 + k13)
  {x1 = - -------------------, x2 = - r theta (k12 r k21 + k21 r k13
             -A + r k11 + r k1i

        + k22 A - r k11 k22 - r k1i k22 + k2i A - r k11 k2i

        - r k1i k2i + k23 A - k23 r k11 - k23 r k1i)/(

                                      r theta (k32 + k33 + k3i)
        A (-A + r k11 + r k1i)), x3 = -------------------------}
                                                  A
```

```
>
> k11:=7/116:
> k1i:=3/116:
> k12:=4/116:
> k13:=18/116:
> k21:=2/116:
> k22:=12/116:
> k2i:=2/116:
> k23:=16/116:
> k31:=0/116:
> k32:=1/116:
> k33:=50/116:
> k3i:=1/116:
> A:=0.23:
> r:=1.5:
> theta:=2:
>

> unassign('r');
> solve({x2 =
> r*theta*(-k12*r*k21-r*k21*k13-k22*A+r*k11*k22+r*k1i*k22-k2i*A+r*k11*k2
> i+r*k1i*k2i-k23*A+k23*r*k11+k23*r*k1i)/(A*(-A+r*k11+r*k1i)), x1 =
> -r*theta*(k12+k13)/(-A+r*k11+r*k1i), x3 =
> r*theta*(k32+k33+k3i)/A},{x1,x2,x3});

                                            r
  {x3 = 3.898050974 r, x1 = -1100. --------------, x2 =
```

```
                                   -667. + 250. r


                                          12                   13
                        -9 r (.8000000000 10   r - .2501250000 10  )
        .5997001499 10   ----------------------------------------}
                                      -667. + 250. r


>
> #### Analysis for Existence:
>
> ## r satisfies local conditions when:
>
> solve(-1100.*r/(-667.+250.*r)<2);

  RealRange(-infinity, Open(.8337500000)),

        RealRange(Open(2.668000000), infinity)

> solve(.5997001499e-9*r*(.8000000000e12*r-.2501250000e13)/(-667.+250.*r
> )>=2);

  RealRange(.8337500000, Open(2.668000000)),

        RealRange(3.335000000, infinity)

> solve(3.898050974*r>=2);
```

```
                RealRange(.5130769231, infinity)

>
>
> ## r satisfies global condition when:
>
> solve(-1100.*r/(-667.+250.*r)>=0);

                RealRange(0, Open(2.668000000))

> solve(.5997001499e-9*r*(.8000000000e12*r-.2501250000e13)/(-667.+250.*r
> )>=0);

  RealRange(0, Open(2.668000000)), RealRange(3.126562500, infinity)

> solve(3.898050974*r>=0);

                      RealRange(0, infinity)

> # The intersection of these sets is [.5130769231,.8337500000) and
> hence only expect an Equilibrium V in this range for r.
>
>
>
>
> #------------------------Equilibrium VI------------------------
> #
```

```
> # x1 >= theta
> # x2 < theta
> # x3 < theta
> #
> # x1' = -A*x1+(k11+k1i)*r*theta+k12*r*x2+k13*r*x3
> # x2' = -A*x2+k21*r*theta+(k22+k2i)*r*x2+k23*r*x3
> # x3' = -A*x3+k32*r*x2+(k33+k3i)*r*x3
> #
> #Solving x1'=0,x2'=0,x3'=0
> unassign('k11','k12','k13','k21','k22','k23','k31','k32','k33','k1i','
> k2i','k3i','A','x1','x2','x3','r','theta');
> simplify(solve({-A*x1+(k11+k1i)*(r*theta)+k12*r*x2+k13*r*x3=0,-A*x2+k2
> 1*(r*theta)+(k22+k2i)*r*x2+k23*r*x3=0,-A*x3+k32*r*x2+(k33+k3i)*r*x3=0}
> ,{x1,x2,x3}));

         k21 r theta (-A + r k33 + r k3i)                        2
{x2 = - --------------------------------, x1 = - r theta (-k11 A
                       %1

                                                              2
      + k11 A r k33 + k11 A r k3i + k11 A r k22 - k11 k22 r  k33

                  2                               2
      - k11 k22 r  k3i + k11 A r k2i - k11 k2i r  k33

                  2                 2            2
      - k11 k2i r  k3i + k11 k23 r  k32 - k1i A  + k1i A r k33
```

```
                                                       2
        + k1i A r k3i + k1i A r k22 - k1i k22 r  k33

                   2                              2
        - k1i k22 r  k3i + k1i A r k2i - k1i k2i r  k33

                   2                 2
        - k1i k2i r  k3i + k1i k23 r  k32 - k12 k21 r A

                   2                 2                 2
        + k12 k21 r  k33 + k12 k21 r  k3i - k13 k21 r  k32)/(%1 A),

                 2
            k21 r  theta k32
       x3 = ----------------}
                   %1

         2                                       2             2
  %1 := A  - A r k33 - A r k3i - A r k22 + k22 r  k33 + k22 r  k3i

                               2             2             2
        - A r k2i + k2i r  k33 + k2i r  k3i - k23 r  k32

>
>
> k11:=7/116:
```

```
> k1i:=3/116:
> k12:=4/116:
> k13:=18/116:
> k21:=2/116:
> k22:=12/116:
> k2i:=2/116:
> k23:=16/116:
> k31:=0/116:
> k32:=1/116:
> k33:=50/116:
> k3i:=1/116:
> A:=0.23:
> r:=1.5:
> theta:=2.0:
>

> unassign('r');
> solve({x3 =
> k21*r^2*theta*k32/(A^2-A*r*k33-A*r*k3i-A*r*k22+k22*r^2*k33+k22*r^2*k3i
> -A*r*k2i+k2i*r^2*k33+k2i*r^2*k3i-k23*r^2*k32), x2 =
> -k21*r*theta*(-A+r*k33+r*k3i)/(A^2-A*r*k33-A*r*k3i-A*r*k22+k22*r^2*k33
> +k22*r^2*k3i-A*r*k2i+k2i*r^2*k33+k2i*r^2*k3i-k23*r^2*k32), x1 =
> r*theta*(k11*A^2-k11*A*r*k33-k11*A*r*k3i-k11*A*r*k22+k11*k22*r^2*k33+k
> 11*k22*r^2*k3i-k11*A*r*k2i+k11*k2i*r^2*k33+k11*k2i*r^2*k3i-k11*k23*r^2
> *k32+k1i*A^2-k1i*A*r*k33-k1i*A*r*k3i-k1i*A*r*k22+k1i*k22*r^2*k33+k1i*k
> 22*r^2*k3i-k1i*A*r*k2i+k1i*k2i*r^2*k33+k1i*k2i*r^2*k3i-k1i*k23*r^2*k32
> +k12*r*k21*A-k12*r^2*k21*k33-k12*r^2*k21*k3i+k21*r^2*k32*k13)/((A^2-A*
```

```
> r*k33-A*r*k3i-A*r*k22+k22*r^2*k33+k22*r^2*k3i-A*r*k2i+k2i*r^2*k33+k2i*
> r^2*k3i-k23*r^2*k32)*A)},{x1,x2,x3});

                              7 r (-667. + 1275. r)
  {x2 = -.6250000000 10  -------------------, x1 = .0001874062969 r
                                       %1

                              15                  15                    15   2
        (.1112222500 10    - .2676337500 10    r + .1032500000 10    r )

                                               2
                                           9  r
        /(%1), x3 = .1562500000 10   ----}
                                              %1

                             11                  11                    11   2
  %1 := .2780556250 10    - .6774218753 10    r + .2726562500 10    r

>
>
> #### Analysis for Existence:
>
> ## r satisfies local conditions when:
>
> solve(.1874062969e-3*r*(.1112222500e15-.2676337500e15*r+.1032500000e15
> *r^2)/(.2780556250e11-.6774218753e11*r+.2726562500e11*r^2)>=2);
```

```
RealRange(.5185342339, Open(.5187886538)),

       RealRange(1.782730341, Open(1.965738568)),

       RealRange(3.109025982, infinity)

> solve(-6250000.*r*(-667.+1275.*r)/(.2780556250e11-.6774218753e11*r+.27
> 26562500e11*r^2)<2);

  RealRange(-infinity, Open(.5185483752)),

       RealRange(Open(.5187886538), Open(1.715901626)),

       RealRange(Open(1.965738568), infinity)

> solve(156250000.*r^2/(.2780556250e11-.6774218753e11*r+.2726562500e11*r
> ^2)<2);

  RealRange(-infinity, Open(.5182569719)),

       RealRange(Open(.5187886538), Open(1.965738568)),

       RealRange(Open(1.973409696), infinity)

>
>
> ## r satisfies global condition when:
```

```
>
> solve(.1874062969e-3*r*(.1112222500e15-.2676337500e15*r+.1032500000e15
> *r^2)/(.2780556250e11-.6774218753e11*r+.2726562500e11*r^2)>=0);

  RealRange(0, Open(.5187886538)),

        RealRange(.5198221774, Open(1.965738568)),

        RealRange(2.072272254, infinity)

> solve(-6250000.*r*(-667.+1275.*r)/(.2780556250e11-.6774218753e11*r+.27
> 26562500e11*r^2)>=0);

  RealRange(0, Open(.5187886538)),

        RealRange(.5231372549, Open(1.965738568))

> solve(156250000.*r^2/(.2780556250e11-.6774218753e11*r+.2726562500e11*r
> ^2)>=0);

  RealRange(-infinity, Open(.5187886538)),

        RealRange(Open(1.965738568), infinity)

> # The intersection of these sets is empty and hence Equilibrium V does
> not exist for any r.
>
```

```
>
>
> #-------------------------Equilibrium VII--------------------------
> #
> # x1 < theta
> # x2 < theta
> # x3 >= theta
> #
> # x1' = -A*x1+(k11+k1i)*r*x1+k12*r*x2+k13*r*theta
> # x2' = -A*x2+k21*r*x1+(k22+k2i)*r*x2+k23*r*theta
> # x3' = -A*x3+k32*r*x2+(k33+k3i)*r*theta
> #
> #Solving x1'=0,x2'=0,x3'=0
> unassign('k11','k12','k13','k21','k22','k23','k31','k32','k33','k1i','
> k2i','k3i','A','x1','x2','x3','r','theta');
> simplify(solve({-A*x1+(k11+k1i)*r*x1+k12*r*x2+k13*(r*theta)=0,-A*x2+k2
> 1*r*x1+(k22+k2i)*r*x2+k23*(r*theta)=0,-A*x3+k32*r*x2+(k33+k3i)*(r*thet
> a)=0},{x1,x2,x3}));

        r theta (A k23 - r k11 k23 - r k1i k23 + k13 r k21)
 {x2 = - --------------------------------------------------,
                                 %1

           r theta (-A k13 + r k22 k13 + r k2i k13 - k23 k12 r)
      x1 = ----------------------------------------------------, x3
                                    %1
```

$$= r\,theta\,(-k32\,r\,A\,k23 + k32\,r^2\,k11\,k23 + k32\,r^2\,k1i\,k23$$

$$- k32\,r^2\,k13\,k21 - k33\,A^2 + k33\,A\,r\,k22 + k33\,A\,r\,k2i$$

$$+ k33\,r\,k11\,A - k33\,r^2\,k11\,k22 - k33\,r^2\,k11\,k2i$$

$$+ k33\,r\,k1i\,A - k33\,r^2\,k1i\,k22 - k33\,r^2\,k1i\,k2i$$

$$+ k33\,k12\,r^2\,k21 - k3i\,A^2 + k3i\,A\,r\,k22 + k3i\,A\,r\,k2i$$

$$+ k3i\,r\,k11\,A - k3i\,r^2\,k11\,k22 - k3i\,r^2\,k11\,k2i$$

$$+ k3i\,r\,k1i\,A - k3i\,r^2\,k1i\,k22 - k3i\,r^2\,k1i\,k2i$$

$$+ k3i\,k12\,r^2\,k21)/(\%1\,A)\}$$

$$\%1 := -A^2 + A\,r\,k22 + A\,r\,k2i + r\,k11\,A - r^2\,k11\,k22 - r^2\,k11\,k2i$$

```
                        2            2                  2
    + r k1i A - r  k1i k22 - r  k1i k2i + k12 r  k21


>
> k11:=7/116:
> k1i:=3/116:
> k12:=4/116:
> k13:=18/116:
> k21:=2/116:
> k22:=12/116:
> k2i:=2/116:
> k23:=16/116:
> k31:=0/116:
> k32:=1/116:
> k33:=50/116:
> k3i:=1/116:
> A:=0.23:
> r:=1.5:
> theta:=2:
>

> unassign('r');
> solve({x2 =
> -r*theta*(-k23*A+k23*r*k11+k23*r*k1i-r*k21*k13)/(A^2-A*r*k22-A*r*k2i-r
> *k11*A+r^2*k11*k22+r^2*k11*k2i-r*k1i*A+r^2*k1i*k22+r^2*k1i*k2i-k12*r^2
> *k21), x1 =
> r*theta*(A*k13-r*k22*k13-r*k2i*k13+k23*k12*r)/(A^2-A*r*k22-A*r*k2i-r*k
```

```
> 11*A+r^2*k11*k22+r^2*k11*k2i-r*k1i*A+r^2*k1i*k22+r^2*k1i*k2i-k12*r^2*k
> 21), x3 =
> r*theta*(k32*r*k23*A-k11*k23*r^2*k32-k1i*k23*r^2*k32+k21*r^2*k32*k13+k
> 33*A^2-k33*A*r*k22-k33*A*r*k2i-k11*A*r*k33+k11*k22*r^2*k33+k11*k2i*r^2
> *k33-k1i*A*r*k33+k1i*k22*r^2*k33+k1i*k2i*r^2*k33-k12*r^2*k21*k33+k3i*A
> ^2-k3i*A*r*k22-k3i*A*r*k2i-k11*A*r*k3i+k11*k22*r^2*k3i+k11*k2i*r^2*k3i
> -k1i*A*r*k3i+k1i*k22*r^2*k3i+k1i*k2i*r^2*k3i-k12*r^2*k21*k3i)/((A^2-A*
> r*k22-A*r*k2i-r*k11*A+r^2*k11*k22+r^2*k11*k2i-r*k1i*A+r^2*k1i*k22+r^2*
> k1i*k2i-k12*r^2*k21)*A)},{x1,x2,x3});

                               13                   12
           r (-.2668000000 10     + .7750000000 10    r)
  {x2 = -2. -----------------------------------------,
                                   %1

                                   13                   13
                r (-.3001500000 10     + .1175000000 10    r)
      x1 = -2. -----------------------------------------, x3 =
                                        %1

      .2998500750 r (

                        14                    14  2                 14
      -.5035850000 10     r + .1032500000 10    r   + .5672334750 10   )

      /(%1)}
```

```
                        13                   13                     12  2
%1 := .4448890000 10   - .4001999999 10   r + .8250000000 10   r

>
>
> #### Analysis for Existence:
>
> ## r satisfies local conditions when:
>
> solve(-2.*r*(-.3001500000e13+.1175000000e13*r)/(.4448890000e13-.400199
> 9999e13*r+.8250000000e12*r^2)<2);

  RealRange(-infinity, Open(.8337500002)),

        RealRange(Open(1.725286130), Open(2.667999999)),

        RealRange(Open(3.125622960), infinity)

> solve(-2.*r*(-.2668000000e13+.7750000000e12*r)/(.4448890000e13-.400199
> 9999e13*r+.8250000000e12*r^2)<2);

  RealRange(-infinity, Open(.8337500002)),

        RealRange(Open(1.725286130), Open(3.125622960)),

        RealRange(Open(3.334999999), infinity)
```

```
> solve(.2998500750*r*(-.5035850000e14*r+.1032500000e14*r^2+.5672334750e
> 14)/(.4448890000e13-.4001999999e13*r+.8250000000e12*r^2)>=2);

  RealRange(.5185342345, Open(1.725286130)),

        RealRange(1.782730337, 3.109025986),

        RealRange(Open(3.125622960), infinity)

>
>
> ## r satisfies global condition when:
>
> solve(-2.*r*(-.3001500000e13+.1175000000e13*r)/(.4448890000e13-.400199
> 9999e13*r+.8250000000e12*r^2)>=0);

  RealRange(0, Open(1.725286130)),

        RealRange(2.554468085, Open(3.125622960))

> solve(-2.*r*(-.2668000000e13+.7750000000e12*r)/(.4448890000e13-.400199
> 9999e13*r+.8250000000e12*r^2)>=0);

  RealRange(0, Open(1.725286130)),

        RealRange(Open(3.125622960), 3.442580645)
```

```
> solve(.2998500750*r*(-.5035850000e14*r+.1032500000e14*r^2+.5672334750e
> 14)/(.4448890000e13-.4001999999e13*r+.8250000000e12*r^2)>=0);

  RealRange(0, Open(1.725286130)),

        RealRange(1.765380600, 3.111955962),

        RealRange(Open(3.125622960), infinity)

> # The intersection of these sets is [.5185342345,.8337500002) and
> hence Equilibrium VII does exist when r is in this range.
>
> #----------------------Equilibrium VIII----------------------------
> #
> # x1 < theta
> # x2 >= theta
> # x3 < theta
> #
> # x1' = -A*x1+(k11+k1i)*r*x1+k12*r*theta+k13*r*x3
> # x2' = -A*x2+k21*r*x1+(k22+k2i)*r*theta+k23*r*x3
> # x3' = -A*x3+k32*r*theta+(k33+k3i)*r*x3
> #
> #Solving x1'=0,x2'=0,x3'=0
> unassign('k11','k12','k13','k21','k22','k23','k31','k32','k33','k1i','
> k2i','k3i','A','x1','x2','x3','r','theta');
> simplify(solve({-A*x1+(k11+k1i)*r*x1+k12*(r*theta)+k13*r*x3=0,-A*x2+k2
> 1*r*x1+(k22+k2i)*(r*theta)+k23*r*x3=0,-A*x3+k32*(r*theta)+(k33+k3i)*r*
```

```
> x3=0},{x1,x2,x3}));

  {x2 = - r theta (r A k22 k33 + r A k2i k33 + r A k2i k3i

        + r A k2i k1i + r A k22 k3i - r A k23 k32 + r A k22 k11

           2                2                  2
        - r  k2i k1i k33 - r  k22 k11 k33 - r  k2i k11 k33

           2                2                  2
        + r  k21 k12 k33 - r  k22 k1i k33 + r  k23 k32 k11

           2
        - r  k2i k11 k3i + r A k22 k1i - r A k21 k12 + r A k2i k11

           2                2                  2
        - r  k22 k11 k3i + r  k23 k32 k1i + r  k21 k12 k3i

           2                2                  2                2
        - r  k2i k1i k3i - r  k21 k13 k32 - r  k22 k1i k3i - A  k2i

           2         /      2
        - A  k22)  /  (A (A  - A r k33 - A r k3i - r k11 A
                  /

           2         2                          2
        + r  k11 k33 + r  k11 k3i - r k1i A + r  k1i k33
```

```
      2
 + r  k1i k3i)), x1 = -

                                                      2
r theta (-k12 A + k12 r k33 + k12 r k3i - k13 r k32)/(A

                                  2            2
 - A r k33 - A r k3i - r k11 A + r  k11 k33 + r  k11 k3i

              2            2
 - r k1i A + r  k1i k33 + r  k1i k3i),

          k32 r theta
x3 = - ------------------}
        -A + r k33 + r k3i

>
>
> k11:=7/116:
> k1i:=3/116:
> k12:=4/116:
> k13:=18/116:
> k21:=2/116:
> k22:=12/116:
> k2i:=2/116:
> k23:=16/116:
```

```
> k31:=0/116:
> k32:=1/116:
> k33:=50/116:
> k3i:=1/116:
> A:=0.23:
> r:=1.5:
> theta:=2:

> unassign('r');
> solve({x2 =
> r*theta*(k32*r*k23*A-k33*A*r*k22-k33*A*r*k2i-k3i*A*r*k22-k3i*A*r*k2i+k
> 1i*k2i*r^2*k33+k1i*k2i*r^2*k3i-k1i*k23*r^2*k32-k12*r^2*k21*k33-k12*r^2
> *k21*k3i+k12*r*k21*A-k1i*A*r*k22+k1i*k22*r^2*k33+k1i*k22*r^2*k3i-k1i*A
> *r*k2i+k11*k22*r^2*k3i-k11*A*r*k2i+k11*k2i*r^2*k33+k11*k2i*r^2*k3i-k11
> *k23*r^2*k32-k11*A*r*k22+k11*k22*r^2*k33+k21*r^2*k32*k13+A^2*k22+A^2*k
> 2i)/(A*(A^2-A*r*k33-A*r*k3i-r*k11*A+r^2*k11*k33+r^2*k11*k3i-r*k1i*A+r^
> 2*k1i*k33+r^2*k1i*k3i)), x1 =
> -r*theta*(-k12*A+k12*r*k33+k12*r*k3i-k13*r*k32)/(A^2-A*r*k33-A*r*k3i-r
> *k11*A+r^2*k11*k33+r^2*k11*k3i-r*k1i*A+r^2*k1i*k33+r^2*k1i*k3i), x3 =
> -k32*r*theta/(-A+r*k33+r*k3i)},{x1,x2,x3});


                     r
  {x3 = -50. ---------------, x2 = .001499250375 r (
             -667. + 1275. r


                          15                     15                  15   2
        -.3460062499 10    r + .1557111500 10    + .1032500000 10    r )
```

```
   /
  /  (
 /

                 12                    12                      12   2
.2224445000 10   - .5085874997 10   r + .1593750000 10   r ),

x1 = -.03000000000

                           13                    13
        r (-.2223333333 10   + .3875000000 10   r)
---------------------------------------------------------------}
                 12                    12                      12   2
.2224445000 10   - .5085874997 10   r + .1593750000 10   r

>
>
> #### Analysis for Existence:
>
> ## r satisfies local conditions when:
>
> solve(-.3000000000e-1*r*(-.2223333333e13+.3875000000e13*r)/(.222444500
> 0e12-.5085874997e12*r+.1593750000e12*r^2)<2);

  RealRange(-infinity, Open(.5182569728)),
```

```
        RealRange(Open(.5231372554), Open(1.973409692)),

        RealRange(Open(2.667999998), infinity)

> solve(.1499250375e-2*r*(-.3460062499e15*r+.1032500000e15*r^2+.15571115
> 00e15)/(.2224445000e12-.5085874997e12*r+.1593750000e12*r^2)>=2);

  RealRange(.5185342350, Open(.5231372554)),

        RealRange(1.782730335, Open(2.667999998)),

        RealRange(3.109025986, infinity)

> solve(-50.*r/(-667.+1275.*r)<2);

  RealRange(-infinity, Open(.5130769231)),

        RealRange(Open(.5231372549), infinity)

>
>
> ## r satisfies global condition when:
>
> solve(-.3000000000e-1*r*(-.2223333333e13+.3875000000e13*r)/(.222444500
> 0e12-.5085874997e12*r+.1593750000e12*r^2)>=0);

  RealRange(0, Open(.5231372554)),
```

```
      RealRange(.5737634408, Open(2.667999998))

> solve(.1499250375e-2*r*(-.3460062499e15*r+.1032500000e15*r^2+.15571115
> 00e15)/(.2224445000e12-.5085874997e12*r+.1593750000e12*r^2)>=0);

  RealRange(0, Open(.5231372554)),

      RealRange(.5356393264, Open(2.667999998)),

      RealRange(2.815510794, infinity)

> solve(-50.*r/(-667.+1275.*r)>=0);

                RealRange(0, Open(.5231372549))

> # The intersection of these sets is empty and hence Equilibrium VIII
> does not exist for any r.
>
>
```

Appendix F: A Mathematical Demonstration of the Bladen Exchange System Processing Information

The purpose of this appendix is to demonstrate how the Bladen exchange system can be conceived of as processing information, specifically storing information.

The premise behind this analysis is that dynamical systems have the capacity to store information and that effort and/or flow stores for this information (or energy) can be identified in all dynamical systems. In what follows, I will identify what can be considered to be flow and effort stores for the Bladen exchange system, and then I will demonstrate that information can be conceived of as being stored in this economic system.

Identification of the Information Flow and Effort Stores in the Bladen Exchange System

Effort and flow stores can be found in all dynamical systems. This phenomenon is mostly studied by those who work with mechanical systems such as engineers (see Wellstead 1979). In theory, though the notion of effort and flow stores extends to all dynamical systems in general and I will identify next what can be seen to be effort and flow stores within the Bladen exchange system. By "stores", I mean mechanisms within the system which can actually be seen as storing information.

1. A mechanism which exhibits flow storage characteristics within the Bladen exchange system is the change in the number of ground stone implements per household in community, C_j, per unit time. This flow storage mechanism has an associated *flow variable* which describes it defined by $\frac{dx_j}{dt}$.

2. A mechanism which exhibits effort storage characteristics within the Bladen exchange system is a given community C_j's contribution in exporting ground stone to a peer community C_i. This effort storage mechanism has an associated *effort variable* which describes it defined by $k_{ij}f(x_j)$.

Accepted among scientists and engineers (Wellstead 1979), there exist two kinds of effort variables and two kinds of flow variables. There exists an effort variable (e) and an effort accumulation variable (e_a). Likewise, there exists a flow variable (f) and a flow accumulation variable (f_a). The accumulation variables are essentially the effort and flow variables integrated and they represent the *actual information* be stored, not just the *amount of information* being stored, which I will discuss shortly. These variables are associated with each community, C_j, and a peer community, C_i, and they can be mathematically described in the following way:

$$e = k_{ij}f(x_j), \; e_a = e_a(t_0) + k_{ij}\int_{t_0}^{t} f(x_j)dt$$

$$f = \frac{dx_j}{dt}, \; f_a = x_j,$$

where it can be recalled from Section 6.2.4 that:

$$f(x_j) = \begin{cases} r\theta & \text{if } x_j \geq \theta \\ rx & \text{if } x_j < \theta \end{cases} .$$

Computing the Quantity of Information and Kind of Information Being Stored Within the Bladen Exchange System

Now that the effort and flow variables along with their associated accumulation variables have been identified in the model of the Bladen exchange system, we can proceed to demonstrate that these variables and the mechanisms within the system that they represent are storing information.

The amount of information stored by the mechanisms of the Bladen exchange system, represented by the variables that were just described, can be denoted by $\mathcal{I}_{ij}$ and can be computed in the following manner:

$$\mathcal{I}_{ij} = \int_{t_0}^{t} ef \; dt = k_{ij} \int_{t_0}^{t} f(x_j) \frac{dx_j}{dt} \; dt = k_{ij} \int_{x_j(t_0)}^{x_j(t)} f(x_j) \; dx_j =$$

$$= k_{ij} \left\{ \int_{x_j(t_0)}^{\theta} rx_j \; dx_j + \int_{\theta}^{x_j(t)} r\theta \; dx_j \right\} = k_{ij} \left\{ \frac{r}{2} x_j^2 \Big|_{x_j(t_0)}^{\theta} + r\theta x_j \Big|_{\theta}^{x_j(t)} \right\} =$$

$$= k_{ij} \left\{ \left[\frac{r}{2} \theta^2 - \frac{r}{2} x_j^2(t_0) \right] + \left[r\theta x_j(t) - r\theta^2 \right] \right\} = k_{ij} \left\{ \frac{r}{2} \left[\theta^2 - x_j^2(t_0) \right] + r\theta \left[x_j(t) - \theta \right] \right\}$$

What this calculation shows is that when the Bladen exchange system is conceived of as a dynamical system, there is a finite *amount* of information being stored in certain mechanisms within the Bladen exchange system. A brief examination of the solution tells us that this amount of information being stored increases as the exchange system evolves, that is, as $x_j(t)$ (i.e. the amount of manos and metates per household in given community) increases.

Whereas this computation shows us how much information is being stored, it also tells us something about what kind of information is being stored. As was discussed in Section 7.1, it was pointed out that the *actual information* being stored in any dynamical system constitutes the dynamical system's states. This is consistent with what was just stated above, that it is the accumulation variables that store the actual information. Looking back at the flow accumulation variable we clearly see that it is indeed the states of the dynamical system represented by the variable $x_j(t)$ that constitute the actual information being stored within the Bladen exchange system (i.e. $f_a = x_j$). The actual information being stored is important to identify since it is the actual information to which individuals involved in the exchange system are likely to have been attuned. By attuning to this information the individual (i.e. in this case an inhabitant of one of the Bladen communities) was allowing himself or herself to *internalize* this information, thereby permitting the individual to *retrieve* representations from the social system.

What was calculated above was the amount of information stored in the mechanism involving a community with respect to only one of its peers, but the total amount of stored information for the community with respect to all of its peers in the system can be calculated by:

$$\mathcal{I}_{+j} = \sum_{i=1}^{m} \mathcal{I}_{ij},$$

for a particular community, C_j. Moreover, the quantity:

$$\mathcal{I}_{++} = \sum_{j=1}^{m} \mathcal{I}_{+j}$$

denotes the total amount of information stored within the entire exchange system.

This all suggests that main information storage mechanism can be seen to be the community and its involvement in exporting ground stone to a peer community. Since there are three peers involved in the Bladen exchange system (i.e. $m = 3$), all three communities with their associated export linkages with their peers are accumulating information such that the entire Bladen exchange system can be seen to be one great information processor, where the information consists of the state values of the system.

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